Saskatchewan
Environment

Monitoring of spawning walleye populations in Lake Diefenbaker (Saskatchewan), 1991 to 2003

Resource Technical Report 2004 - 1

By
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and
Ronald E. Jensen

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Resource Stewardship Branch
Saskatoon and Swift Current, Saskatchewan
Canada

EXECUTIVE SUMMARY

Saskatchewan has a stocking program to restore and supplement walleye populations. Each spring, walleye are caught in trap-nets and held a few days for ripening, eggs are collected and fertilized on location, incubated at the provincial Fish Culture Station, and distributed as fry.

Coteau Bay on Lake Diefenbaker has been the provincial source of walleye eggs since 1991. About 600 or so mature females provide about 100 million eggs annually. This population was judged biologically healthy in 2000, but there were potential side-effects on nearby populations. These could be serious if large influxes of spawners were masking declines in Coteau Bay.

The objectives of this study were to monitor existing and new biological indicators ('egg quality' and stress from handling) in Coteau Bay, compare sizes and ages of several nearby populations, assess movements among spawning sites, and examine whether rainbow trout have affected walleye growth.

Crews examined spawning populations in three areas: two creeks near Qu'Appelle dam, two bays near Birsay, and Coteau Bay. They trap-netted walleye each spring, counted and measured all walleye, and collected dorsal spines and samples of eggs from some. Several types of tags were applied to obtain estimates of abundance and detect movements from year to year.

Monitoring of hatchery operations at Coteau Bay showed there were very few notable trends or fluctuations since 1991 in catch rates, sex ratios, eggs per female, or other indicators. One indicator did fluctuate significantly: percentage of female walleye in the catch was very low in 2000, although it rebounded in 2001. The proportion of females is important to the population and our interests, and should be watched.

Generally, heavier walleye eggs produce heavier fry, which presumably survive better in the wild. Samples of eggs were collected from almost 150 walleye in 2002, and dried and weighed to obtain 'egg dry mass'. Eggs from Coteau Bay weighed the same in 2002 as in 1997 during an earlier study, and the same (or more) as those from other spawning sites.

The presence and severity of the virus 'lymphocystis' is an index of stress. This virus causes warts in the skin or fins of walleye. It often flares up when fish are stressed by spawning or handling, then recedes in warmer weather. Observations of almost 6,000 walleye showed a background rate of about 3% in Lake Diefenbaker. Handling of fish for egg collection and for tagging both caused higher rates, almost 10% in Coteau Bay. Hatchery crews now release infected walleye at trap-nets rather than holding them. Assessment crews do not plan any more tagging.

Female walleye ranged up to 77 or 81 cm long (about 30 inches) and up to age 18 to 20. Males were smaller and younger, which is typical of walleye populations. Both females and males in the Qu'Appelle area were longer than those at Birsay, which were similar to those in Coteau Bay. The size and age compositions and mortality rates indicated healthy walleye populations.

Ages and growth patterns were based on dorsal spines from about 1,000 walleye. The 1990 year-class was relatively strong while 1993 and 1994 were relatively weak. These variations are natural for walleye, since reproduction and survival are affected by spring temperatures and summer growing conditions. Growth patterns in age-6 to age-10 female spawners implied that fast-growing individuals matured earlier. Therefore, the available data were unsuitable for detecting impacts by rainbow trout on walleye growth.

Spawner abundances averaged almost 6,000 walleye at Qu'Appelle area, nearly 3,000 at Birsay, and 10,000 to 12,000 at Coteau Bay. This suggests that there may be many more spawning sites than we know, or that Lake Diefenbaker may have a much lower density of mature walleye than expected and protecting them becomes more important.

About 90% or more of tagged walleye returned to the same spawning site in the next spring. There may be a small influx of 800 to 1,000 spawners into Coteau Bay each year from other sites, although movements may be 'balanced' since these estimates are imprecise.

Our assessment is that all of the spawning populations examined are biologically healthy. Nonetheless, there is no way to prove this beyond any doubt, the situation may change over time, and our assessment is less reliable for sites far from the study area.

Several of our recommendations follow:
— Base the annual collection of walleye eggs on their availability, rather than demands. This should ensure their sustainability, but may require a review of provincial uses of walleye fry.
— Continue to monitor operations in Coteau Bay, especially walleye catch rates, the proportion of females, average eggs per female, and percentage hatch each year. Monitoring of 'egg quality' and viral and other disease symptoms ever three to five years should suffice.
— Design a contingency plan for hatchery operations to ensure a timely response if problems arise. This should include criteria for action and alternative management scenarios.
— Continue to mark hatchery fry that are re-stocked into Coteau Bay, and determine their contribution to the young walleye population.
— Monitor angling at tournaments and other sites to estimate harvests and effects of fishing.
— Consider a survey to assess the abundance and sizes of walleye and other species in different areas of this lake.

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Fish Culture Station staff provided working facilities and modified their procedures for us. Greg Mitchell, Shawn Baldock, Jerry Banks, and other staff provided records of their own operation and tag numbers and other information on recaptured walleye.

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INTRODUCTION

Saskatchewan has a stocking program to restore and supplement natural walleye (*Sander vitreus,* formerly *Stizostedion vitreum*) populations and to provide anglers with new fishing areas. For decades, eggs have been obtained from spawning walleye at field camps at various sites in April and May, fertilized on location, and transported to the provincial Fish Culture Station (FCS) at Fort Qu'Appelle for incubation and later distribution of fry.

Since 1991, Coteau Bay on Lake Diefenbaker has been the sole source of walleye eggs. Each spring up to 6,000 walleye are caught in trap-nets by hatchery crews over three weeks or so. Between 60 and 110 million eggs are collected annually for province-wide use.

The health of the Coteau Bay population itself was assessed in 2000 (Jensen and Wallace 2001), but concerns remained. Conditions of other populations and movements of spawners among sites were unknown. There could be serious effects lake-wide if mixing of spawners has been masking declines in Coteau Bay. Effects would be more serious if influxes provide large numbers of walleye to Coteau Bay, or the lake has fewer walleye than expected, or there are only a few spawning sites. Warning signs might not allow much time for management response and populations would decline lake-wide, rather than in Coteau Bay alone.

Further, slow declines over time of "egg quality" (usually egg sizes or percent hatch) or increased symptoms of disease and handling have been noted in some long-term operations. These could have serious effects on both walleye populations and our hatchery program. So baseline conditions were monitored using indicators of stress, necropsies of a few specimens, and a modified index of egg size.

The objectives in this study were to assess the status of spawning populations, by:
— assessing movements of walleye among spawning sites, especially major in-flows of spawners into Coteau Bay;
— monitoring additional indicators ('egg quality' and symptoms of stress from handling);
— comparing sizes and ages and other traits of the Coteau Bay population to others;
— examining whether escapes of rainbow trout have affected growth patterns in walleye.

This report begins by updating the monitoring of operations at Coteau Bay and analyzing new indicators of egg quality and stress at several sites. Then, size and age compositions are compared for several spawning sites. Finally, abundances of spawners and their mixing are assessed after adjusting for mortality, tag loss, and other factors.

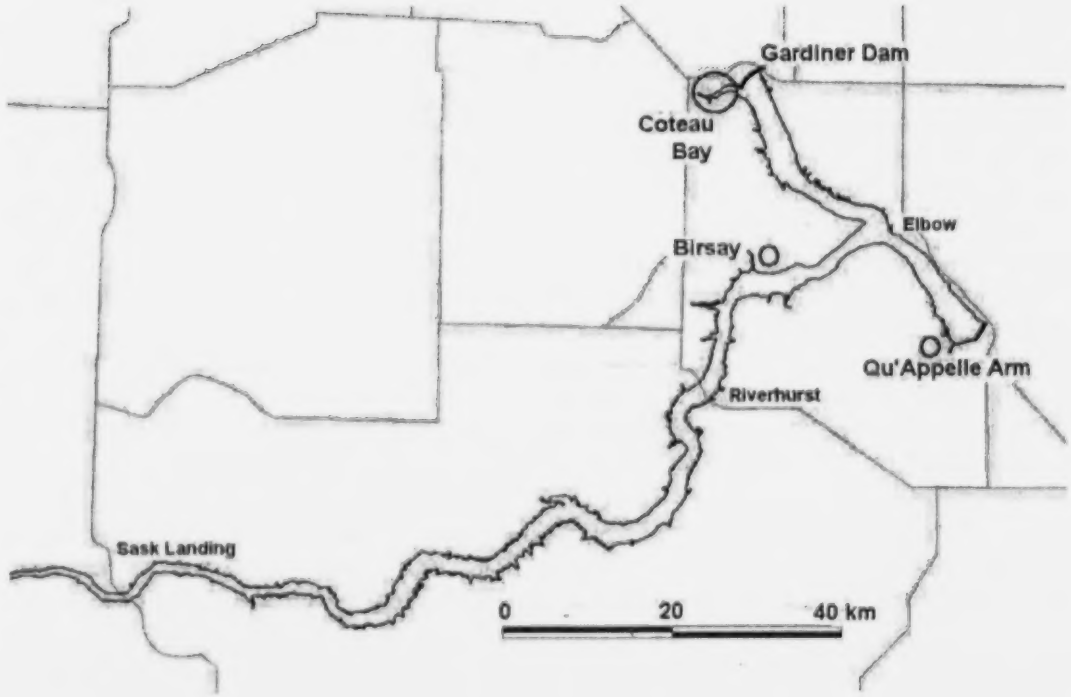

Figure 1. Map of Lake Diefenbaker, Saskatchewan. Spawning sites at Coteau Bay, Qu'Appelle Arm area, and Birsay area are shown as circles; some other locations are named. Outflows from Gardiner Dam continue down the South Saskatchewan River; outflows from Qu'Appelle Dam go into the south-eastern water-control area.

SITES

Lake Diefenbaker is a 35-year-old reservoir on the South Saskatchewan River, extending 222 km from Gardiner Dam upstream past Sask Landing (Figure 1). The lake is 430 square km and has 760 km of shoreline (Royer 1972, Saskatchewan Environment 1988). About half the lake is more than 15 m deep and one-quarter more than 30 m. Average depths are 30 m near the dam and 14.6 m up-lake. Over-winter drawdowns for hydro power are typically 3 to 11 m.

There were three main study areas, each with one or two nearby field sites:
— Coteau Bay is beside Gardiner Dam and spillway, and five km long and about one km wide under spring conditions (Figure 2, from Royer 1972);
— Qu'Appelle Arm sites were two small creeks (Aiktow Creek and Summit, also known as Fordes, Creek) in a bay near the dam;
— Birsay area includes Hitchcock Bay on the northern shore and Sage Bay across on the southern side.

All sites were fished using trap-nets of 6 to 8-foot mouths by crews in late April to early May. Nets were typically set in water 2 to 4 m deep on flat or mildly sloping bottoms. Our trap-nets are not usually rigged for very deep water, and trap-nets are not effective on steep slopes.

Assessment crews at Coteau Bay worked along-side FCS staff from Fort Qu'Appelle. The latter fished four or five trap-nets and retained most walleye (up to 3 days only). Assessment crews examined, measured, tagged, and collected ageing or other samples just prior to their release. The large number of walleye available required some sub-sampling of batches.

Assessment crews fished at Qu'Appelle and Birsay areas with similar trap-nets for two to three weeks, usually in areas 2 to 3 m deep with low to moderate gradients. Fishing usually began a week later than in Coteau Bay because open, ice-free conditions at these sites occurred later. Boat launch sites are limited and access was difficult in many areas due to recent low water-levels.

The assessment crew fishing at Qu'Appelle (AC and SC) stayed at Douglas Provincial Park and commuted by road. In some springs, walleye are on-site before boat travel across the lake is possible. In 2003, this crew used Riverhurst Regional Park to access and trap-net at Hamilton Flats. The crew working at Birsay (HB and SB) stayed at Hitchcock Hideaway, accessed the lake locally, and boated to Sage Bay daily.

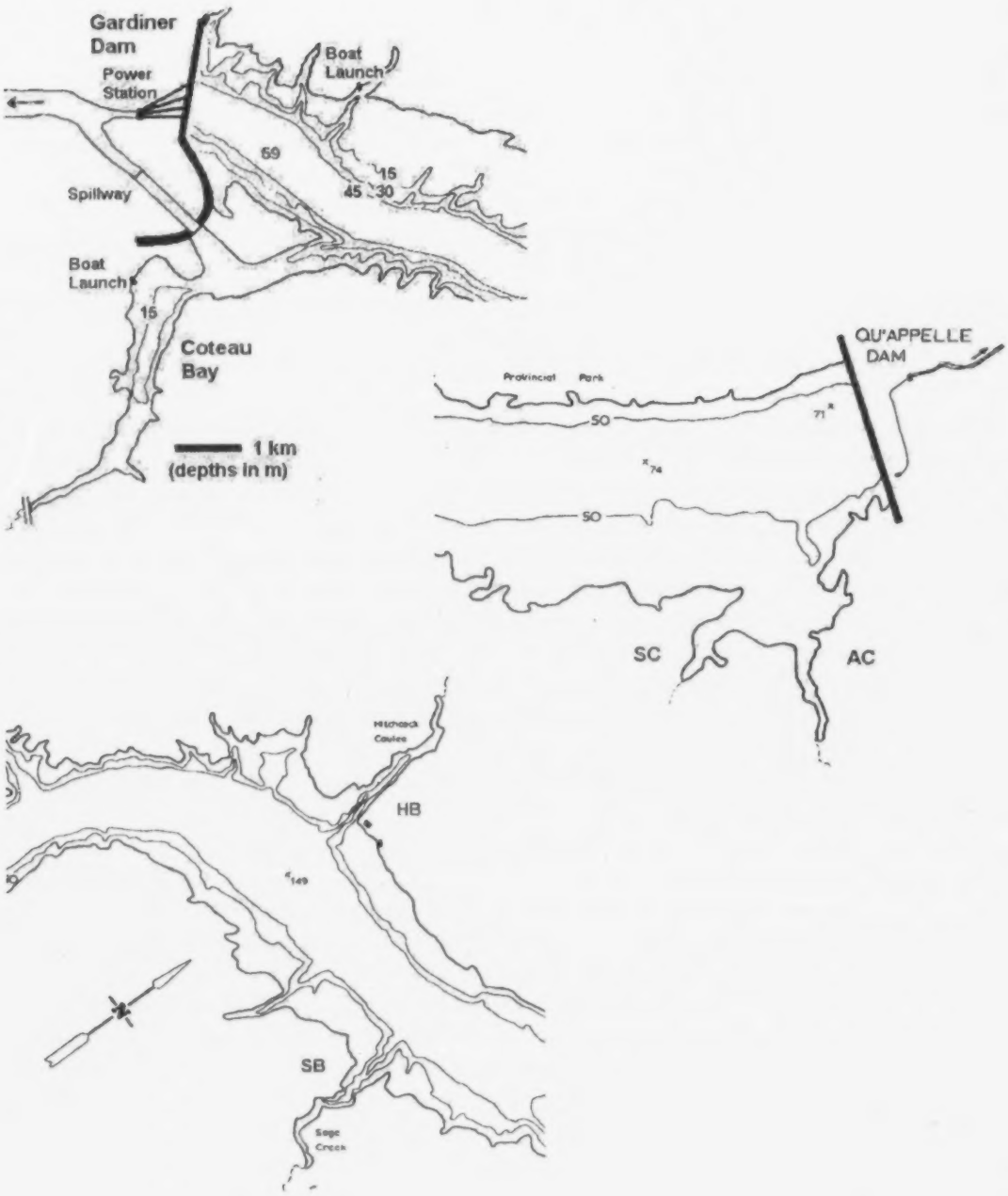

Figure 2. Map of Coteau Bay, Qu'Appelle, and Birsay areas. Spawning sites include Coteau Bay (CB), AC (Aiktow Creek), SC (Summit Creek), HB (Hitchcock Bay), and SB (Sage Bay).

FCS MONITORING

INTRODUCTION

Fish culture staff catch walleye and collect eggs in Coteau Bay during late April to mid-May. They set four or five trap-nets near the same locations (typically 2 to 3 m deep with low gradients) each year and check them daily. All fish species are counted, walleye are retained, and other species are released at the nets.

Staff transport walleye by boat to shore in aerated tanks. They are visually sorted into ripe and running or unripe ("green") groups. Eggs and sperm are manually stripped from ripe and running fish. Green females are held in pens up to three days for ripening, before being released back into Coteau Bay. Fertilized eggs are clayed and rinsed, water-hardened, and retained on-site in floating baskets until transported to the hatchery at Fort Qu'Appelle.

Since 1991, hatchery staff have monitored several indicators of walleye abundance and condition. These include numbers of walleye (females and males) caught, numbers of females used for eggs, number of eggs per female, and percentage of eggs hatching.

These indicators were analyzed visually and statistically, to determine if there were significant trends up or down over time, or if individual years fluctuated outside reasonable bounds.

METHODS

Daily records of catches were compiled by FCS staff, and were checked and clarified as necessary (Greg Mitchell, Shawn Baldock, and Jerry Banks pers comm). Data for each day and trap-net were available during operations, but they were analyzed as annual totals.

Linear regressions were used to detect significant trends of indicators over the years, or individual years outside the confidence or prediction bands ($P<0.05$, NWP 1998). Confidence bands provided the expected range for several data, while the wider prediction bands showed limits for a single observation. Patterns in the fluctuations of years were examined for notable anomalies, but none were excluded from analysis ("studentized residuals" in NWP 1998).

Time-series analysis was used to show the degree of auto-correlations (ACF) from year to year. ACF coefficients show the correlation between year 't' and year 't + k' (called lag of k). Positive coefficients mean that indicators agree for these years, either both higher or both lower. A frequent example is higher catches of fish occurring one year and for several following years.

RESULTS

Hatchery staff caught about 2,200 male and 1,500 female walleye on average each year. Females comprised a relatively high 43% of the walleye catch, a "sex ratio" of 1.3 male: 1 female. The average of 660 females spawned each year produced 90 million eggs and 48 million fry after hatching (Table 1).

Trap-netting effort varied by about 2-fold and water-levels on May 1st varied by 4 m over the 13 years. Multiple linear regression of total walleye catches showed that higher water-levels reduced catches somewhat, as reported by hatchery staff previously:

Numbers of walleye = 45082 - 78.73 WL (water-level m) + 35.05 TNN (trapnet-nights)

More effort increased catches as expected, but effective effort is not well defined. Hatchery staff relocate nets and otherwise work to improve catches and maintain reasonable numbers of females and eggs in poor years. They can only improve catch rates in good years so far before stretching the capacity of pens, hands-on care, and transportation. In any case, the effects of both WL and TNN are non-significant (P=0.76 and P=0.12 for slopes, respectively, NWP 1998) These two factors explained only 12 % of the variation in this relatively short time-series. Using the logarithms of numbers did not explain the variations in walleye catches any better.

Catches of female walleye is an important goal during operations. Higher water-levels reduced these catches even more, while greater effort had less effect:

Number of females caught = 60376 - 107.45 WL + 8.46 TNN

This equation implies that for every m of higher water, catches decrease by 107 females. For every extra trap-net fished for two weeks, catches increase by 118 females. About 22 % of variations were explained and both component slopes were again non-significant (P=0.17 and P=0.19, resp.).

Linear regressions did not reveal any significant trends over time in the other five indicators. Most of the regressions were poor fits, so the lack of trends was hardly conclusive (Table 2).

A few of the seven indicators were very high or very low in some years, falling outside the prediction bounds (Table 2). For example, 'Females caught' were very high in 1999 and 'Females spawned' very low in 1995. However, the latter may indicate a greater demand for eggs, rather than natural abundance of females itself.

'Female %' rebounded from very low in 2000 to 'normal' in 2001 and even high in 2002 and 2003 (Figure 3). This index does show significant short runs of years going up and down, rather than random fluctuations each year (P=0.007 in runs-test, NWP 1998). This and the ACF coefficients suggest that female abundance may reflect weak-year classes about 1992 to 1994 (see 'Sizes and Ages').

Most time-series patterns seen were those expected in fish populations. Many indicators in Coteau Bay showed moderate positive ACFs at lag 1 and smaller negative ACFS around lags 5 to 8. In many populations, this is due to strong year-classes (resulting from good abundance of spawners, conditions during spawning, and survival and growth of young fish) or to suitable fishing conditions which persist for several years.

Although spawners in Coteau Bay are long-lived, strong year-classes are still influential: the first 2 year-classes that were fully recruited comprised 38% of spawners, the same proportion as all ages from 10 to 19. Any year-class which is 2-fold or 5-fold above average abundance (which is not unrealistic for walleye) will have notable effects on catches, although this was not statistically significant in Coteau Bay.

'Eggs collected' shows a smooth increase up to 1995-1997 and then a similar decline. This is likely due to hatchery operations building in early years, followed by increasing demand for eggs as 'quotas' were met, and then a decline in demands (Greg Mitchell pers comm).

These indicators can be shown graphically, although details are lost. Since data ranges are very large (from percent to thousands), each series was divided by its own average (Figure 4).

Some of the other fish species caught during trap-netting showed more-or-less steady abundance, varying up and down by 2-fold or so (such as northern pike and lake whitefish, Table 3). But others showed wide variations or obvious trends. White suckers showed a sudden 3-fold increase in 2001. Other sucker species (including longnose sucker, quillback, shorthead redhorse, and silver redhorse) comprised only several hundred specimens collectively each year and are not shown.

Rainbow trout increased 10-fold in 2000 due to the escape of 400 thousand from aquaculture operations near Birsay (Tom Maher pers comm). They then declined to their original numbers in catches by 2002. Burbot declined seriously in the mid-1990s and continue to dwindle. Cisco have not been reported in recent years, while yellow perch are more numerous. The riverine goldeye has been steady (in low numbers), but mooneye and other stocked trout species are negligible.

Table 1. Numbers of walleye and eggs, netting effort, and water-levels each year at Coteau Bay, 1991-2003 [a].

Year	Number of walleye				Number of eggs			Trap-netting effort	Waterlevel (FSL=557)	Fry stocked
	Males	Females	Females (as %)	Females spawned	Collected	Per female	Hatched			
					(millions)	(thousands)	(%)	(net-nights)	(m)	(millions)
1991	1754	1478	46	484	60.9	125	56	40	549.9	2.3
1992[c]	...	...	...	...	...	...	...	...	551.3	...
1993	1738	1351	44	525	78.4	149	56	36	554.0	2.2
1994	2464	1731	41	642	97.7	152	51	44	552.3	3.0
1995	1395	1569	53	918	112.9	123	45	85	550.9	3.4
1996	1278	1072	46	648	93.7	145	51	56	553.8	3.5
1997	1947	1424	42	679	113.0	166	57	55	553.4	3.4
1998	2657	1696	39	768	105.0	136	52	65	552.6	3.5
1999	3938	2518	39	717	99.5	140	49	85	550.7	6.0
2000	3868	1181	23	649	96.7	149	55	75	553.3	3.5
2001	3008	2128	41	832	93.5	112	48	75	551.7	3.6
2002	1219	1368	53	704	85.3	121	57	67	550.4	5.2
2003	986	1241	56	595	68.7	115	58	55	553.7	4.0
Average	2153.7	1551.7	43.7	666.6	90.4	136.2	53.2	59.7	552.2	3.6
Min	986	1072	23	484	60.9	112	45	36	549.9	2.2
Max	3938	2518	56	918	113.0	166	58	85	554.0	6.0

[a] Data are from Fish Culture Station annual records.

[b] Water-levels are for May 1st each year (Martin Grajczyk, Sask Watershed Authority pers comm)

[c] There were no operations in 1992, so the average of 1991 and 1993 was used in regressions and time-series analyses.

Table 2. Summary of analysis of indicators in hatchery operations, Coteau Bay 1991 to 2003.

Index	Average (95% CI) [a]	Linear regression			Years outside CI [a]		Years outside PI [a]		ACF coeffs [a] and notes
		r^2 (%)	Slope [a]	Prob [b]	Low	High	Low	High	
Walleye caught	3810 (3078 to 4541)	10	96.9 (-99 to 293)	0.30	2003	1999	nil	nil	NS, +ve @ lag 1 & -ve @ lags 3&4
Females caught	1552 (1311 to 1792)	2	12.8 (-54 to 80)	0.68	1996, 2000	1999, 2001	nil	1999	NS, only small
Females (% of catch)	43.7 (38.7 to 48.7)	0	-0.005 (-1.4 to 1.4)	0.99	2000	1995, 2002, 2003	2000	nil	NS, +ve @ 1 and -ve @ 3&5; "Runs" non-random
Females spawned	667 (590 to 743)	20	14.4 (-4.8 to 33.7)	0.13	2003	1995, 1998, 2001	nil	1995	NS, +ve @ 1 and -ve @ 8
Eggs collected (millions)	90.4 (80.2 to 100.5)	5	0.92 (-1.9 to 3.7)	0.48	1991, 2003	1995, 1997, 1998	nil	nil	NS, +ve @ 1 and -ve @ 5; "+/- Median" is non-random
Eggs per female (thousands)	136.5 (126 to 146)	13	-1.49 (-4.1 to 1.07)	0.23	1991, 1995, 2001	1997, 2000	nil	nil	NS, +ve @ 1&3 & -ve @ 5&9
Hatch rate (% of eggs)	53.2 (50.7 to 55.6)	10	0.03 (-0.7 to 0.7)	0.92	1995, 1999, 2001	1997	nil	nil	NS, +ve @ 6 and -ve @ 2&8

[a] 95% confidence interval (CI) for average, slope, and outliers; 95% prediction interval (PI) for outliers.

[b] Probability that slope is not zero (Prob < 0.05 would indicate a significant trend up or down).

[c] Time-series auto-correlations and partial auto-correlations are all non-significant.

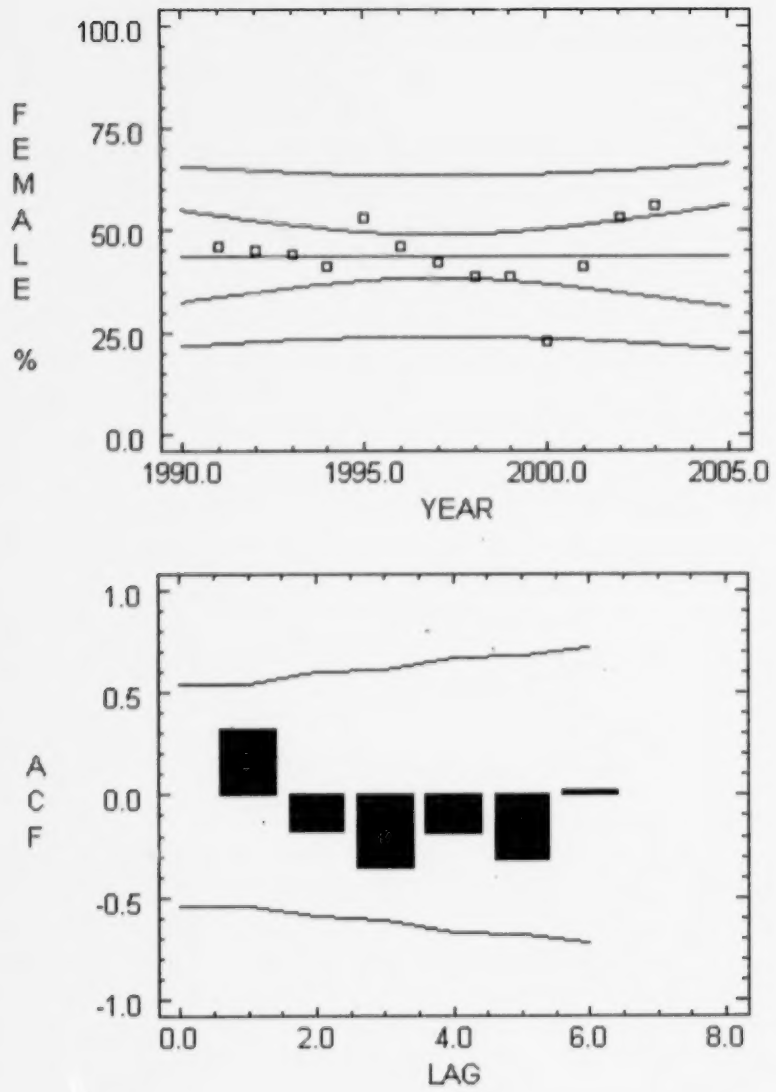

Figure 3. Proportion of females (as %) in catches in Coteau Bay, 1991 to 2003.
UPPER: Regression line showing several years above the confidence band (inner pair of lines) and year 2000 below the prediction band (outer pair of lines, see text).
LOWER: Auto-correlations between years and 1 to 10 years later (solid bars); bars inside the confidence lines are non-significant statistically (see text).

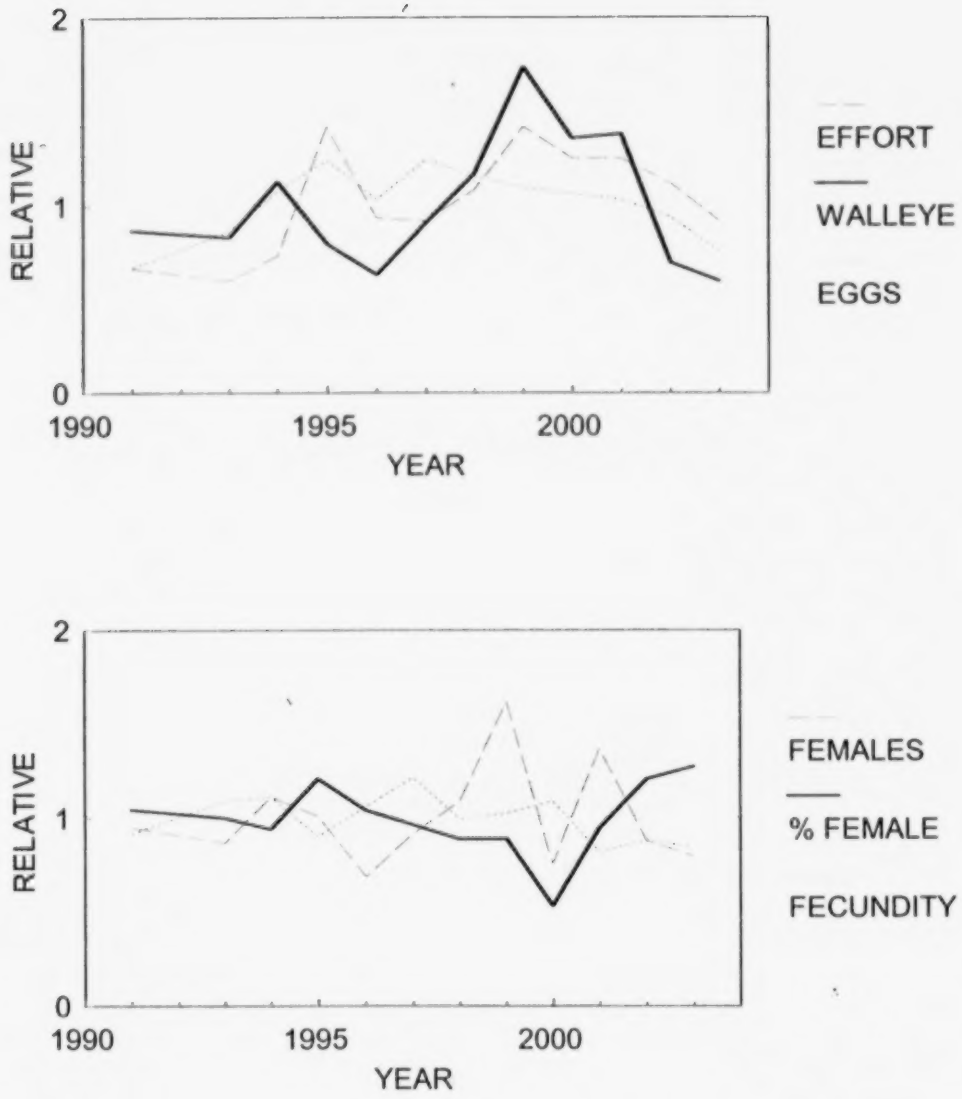

Figure 4. Fluctuations in indicators of walleye in Coteau Bay, 1991 to 2003.
Data taken during hatchery operations are shown relative to their own means.
UPPER: total trap-netting effort, abundance, and eggs collected.
LOWER: number of females caught, % females in catches, and eggs per female.

Table 3. Fish species caught in Coteau Bay during hatchery operations, 1991 to 2003. [a]

YEAR	NRPK	WHSC	LKWH	RBTR	BURB	CSCO	SAUG	YLPR	GOLD	MOON	ATSL	BKTR
1991	98	790	248	0	17	2	1	0	1	0	0	0
1992	...	...	...	...	...	...	...	.....	...	...	...	...
1993	874	1490	287	0	62	0	0	0	7	0	0	0
1994	906	1771	216	21	182	6	1	0	2	0	0	1
1995	765	3425	425	54	106	18	1	5	1	0	2	0
1996	529	1497	431	27	20	24	0	0	10	10	1	0
1997	275	3327	938	57	32	1	1	0	5	1	2	0
1998	598	4040	843	93	16	51	1	5	5	0	2	0
1999	957	5898	1462	86	10	113	3	260	0	0	0	0
2000	720	5903	1318	939	4	0	1	66	16	0	1	0
2001	262	16255	1098	345	8	0	17	352	32	0	2	0
2002	347	17328	220	106	9	0	1	43	68	0	0	0
2003	159	10689	471	177	4	6	0	48	92	0	0	0
Mean	540	6034	663	159	39	18	2	65	20	1	1	0
Min	98	790	216	0	4	0	0	0	0	0	0	0
Max	957	17328	1462	939	182	113	17	352	92	10	2	1

[a] NRPK is northern pike (*Esox lucius*), WHSC white sucker (*Catostomus commersoni)*, LKWH lake whitefish (*Coregonus clupeaformis)*, RBTR rainbow trout (*Oncorhynchus mykiss)*, BURB burbot (*Lota lota*), BKTR brook trout (*Salvelinus fontinalis)*, ATSL Atlantic salmon (*Salmo salar*), GOLD goldeye (*Hiodon alosoides*), MOON mooneye (*H. tergisus)*, SAUG sauger (*Sander canadense*), YLPR yellow perch (*Perca flavescens)*.

The lack of yellow perch until 1999 and large sucker numbers until 2001 may suggest changes in lake-wide or Coteau Bay conditions, in recent spring weather, or timing of hatchery operations. Most years, records show sucker catches peak before walleye. However, this does not likely explain yellow perch abundance and new conditions in Coteau Bay since mid-1990s may suit these species better.

DISCUSSION

The lack of any significant trends over time indicates that the Coteau Bay spawning walleye population is biologically healthy. There is no indication of problems with walleye abundance, "sex ratios", or egg availability according to the data. Several indicators fluctuated notably, sometimes two or more in a year. But this is expected, since there may be a few data-points that stand out randomly when many comparisons are done.

The only concern among the seven indicators was the very low 'Female %' in 2000, and it has since improved. Its tendency to fluctuate in short runs may reflect the passage of strong and weak-year classes. This implies that observing a low 'Female %' in a single year may not indicate the beginning of a real decline. If two or more years are required, then management reaction to protect female spawners is more difficult if it becomes necessary. Time series often do not provide solid evidence of small to moderate changes in populations unless they are impractically long and detailed.

All of the available indicators cannot prove this population will remain healthy. By 2000, the idea of capping demands and fine-tuning collections to the number of females and eggs available, was being discussed by FCS staff and others. A contingency plan and a suite of criteria that trigger action seem fairly important. Several possibilities are discussed below (see general 'Discussion').

Explaining the reasons for some of the variations observed in several indicators is difficult. The patterns of auto-correlation noted for Coteau Bay walleye are similar to other walleye populations. Simulations indicate that high positive ACFs at a lag of 1 year in walleye abundance are probably due to density dependence (Jensen 1999, using similar PACFs).

If abundance is near the 'carrying capacity' of a lake, having many adult age classes tends to reduce variations in recruitment so that year-to-year changes are gradual. The abundance in any year is best predicted by the abundance in the previous year, so catches show high positive ACF. In his simulations of Red Lakes walleye, Jensen (1999) used 14 age classes, similar to the 10 age classes in males and 13 in females in Lake Diefenbaker (see 'Sizes and Ages').

On the other hand, an ACF at lag of the age of maturity is more complex and probably related to larval survival (Jensen 1999). Simulations suggest this ACF tends to be negative when larval survival is high since limited food means higher mortality in young-of-the-year and juveniles, which lessens recruitment to adulthood several years later. When larval survival is low, the ACF tends to be positive and recruitment increases later. These simulations, of course, are based on the variations between years, rather than overall trends in abundance over time.

A related effect was observed regionally in Wisconsin walleye populations (Beard et al. 2003). Adult abundance and climate had some effect, but predation by yellow perch (*Perca flavescens*) only affected walleye density in low-recruitment years. In high-recruitment years, they were able to withstand predation.

Nonetheless, a negative ACF at a lag of several years may not be related to density-dependence at all. A review of walleye populations in the Great Lakes and several inland lakes showed that "community dynamics" (especially prey abundance) were important in eutrophic lakes, while environmental factors (e.g. river flows or spring temperatures) were more important in oligo-trophic lakes (Reckahn and Thurston 1991). Since Lake Diefenbaker is considered meso- or oligo-trophic in the central and lower part around our study areas, environmental factors may dominate. The upper part near Sask Landing is more eutrophic (based on phosphorus and "chlorophyll a" data from 1984-85 and OECD criteria, ILEC 1999), where community dynamics may dominate. So auto-correlation patterns may vary within the lake or over time with changes in reservoir conditions.

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EGGS AND FRY

INTRODUCTION

Studies have shown that larger walleye eggs produce larger fry, which are assumed to have better survival and growth in the wild. In turn, egg size is often related to size and age, and inversely to growth rate of spawners. Relationships are better shown when size is measured as the dried weight of eggs and fry, rather fry length (r2=0.94 versus 0.34, Johnston 1997).

'Egg dry mass' (EDM) seemed like a useful and simple index for monitoring egg quality. Samples from Coteau Bay in 1997 had been analyzed as part of a North American survey (Johnston 1997). Other factors such as lipid content, ash content, and energy density of eggs would be much more technically difficult.

The survival and contribution of fry, which are re-stocked annually from the hatchery into Lake Diefenbaker, is unknown. The assumption is that the percentage of eggs hatching at the hatchery (with controlled water temperatures and preventative disease treatments) is better than in the wild.

METHODS

In 2002, egg samples were collected from ripe females with free-running or easily expressed eggs. We aimed to collect about 50 samples for each site from a range of female sizes. Basically, 50 to 100 ml of eggs were collected from the first few hundred eggs available, frozen within an hour (or chilled with ice until frozen later in the day at some sites), and stored frozen. This method was modified from Johnston (1997), who was analyzed his samples without freezing.

Egg samples were thawed and small portions swirled in water to release free eggs. Two sub-samples of 30 eggs each were counted, excluding deformed or 'wrinkled' (presumably dehydrated) eggs. They were dried on small pre-weighed aluminum foils at 60C about 24 hours, desiccated an hour, and weighed to 0.0001 g on a Mettler Model-H6T balance (Johnson 1997). If sub-samples differed by more than 10%, the sample was redone.

The EDM were plotted and regressed against female fork lengths (both raw and $\log_e$ transformed), and female ages if available.

Since 2000, walleye fry have been marked by immersion in tetracycline solution (Hlasny and Murphy 2001). This will allow hatchery fish to be identified by fluorescent marks in their otoliths.

RESULTS

About 150 egg samples were collected in 2002 from the different areas:
Coteau Bay 46, Aiktow Creek 24, Hitchcock Bay 24, Summit Creek 37, Sage Bay 17.
However, about 14 samples from Aiktow Creek and 16 from Summit Creek were lost due to a freezer malfunction. A few fish also did not have one of length, weight, or ageing material collected for various reasons.

There were some problems observed with our methods. Field crews reported some difficulty keeping eggs chilled on some days, although we excluded ruptured or dehydrated eggs later. We also observed some oil globules in thawed samples, but these appeared to be from complete ruptures rather than partial leakage. A very few EDM were judged to be possible statistical outliers (about 6 of 108 depending on criterion used, NWP 1998), but they were left in the dataset to avoid bias. Coteau Bay showed one notably high EDM and all sites (except Aiktow Creek) showed at least one low EDM.

Female walleye used for EDMs ranged from 394 to 765 mm long and EDMs ranged from 0.293 to 1.412 mg (Table 4). Since these specimens were selected to represent a range of sizes, they do not reflect the general size composition of females.

The median EDMs of some of the sites differ statistically, with indications that they are higher in Coteau Bay than Aiktow Creek:

Site	Count	Mean rank	Test statistic = 15.4975
CB (Coteau Bay)	42	67.9	P-Value = 0.00377
AC (Aiktow Creek)	10	28.6	
SC (Summit Creek)	20	51.8	
HB (Hitchcock Bay)	20	50.2	
SB (Sage Bay)	17	48.0	

(non-parametric Kruskal-Wallis test at 5%).
However, this KW-test is not useful in determining which pairs differ.

Although fork length and EDM data were both statistically non-normal, we also used normal tests to elicit further details:

(1) Comparisons of pairs of sites showed that the only significant difference was that EDMs were larger in Coteau Bay than Aiktow Creek (Figure 5). Since we were comparing several pairs of sites, we used the 'Bonferroni test' to minimize false differences appearing randomly, which would occur in 1 case out of 20 comparisons otherwise.

Table 4. Summary of fork lengths of females and egg dry mass, by site 2002.

Site [a]	Count	Mean	Median	Minimum	Maximum	CV%
Fork Lengths (mm)						
CB	42	595.8	603	435	765	16
AC	10	599.1	577	500	763	14
SC	20	603.3	610	495	716	11
HB	19	574.1	568	394	668	11
SB	17	564.7	554	436	746	18
Egg Dry Mass (mg)						
CB	42	0.928	0.920	0.718	1.412	13
AC	10	0.746	0.797	0.400	0.907	21
SC	20	0.845	0.868	0.463	1.072	18
HB	20	0.838	0.853	0.465	1.168	19
SB	17	0.831	0.833	0.293	1.033	20

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, and SB Sage Bay.

(2) We used ANOVA tests to compare the variation between-groups and within-groups. If the former is much larger than the latter (based on the F-ratio), the probability of such a ratio arising by chance is low (P-value < 0.05). There were no significant differences among sites in the sizes of females selected for EDM samples. There were, however, significant differences in EDMs between sites (Table 5).

(3) Adjusting for small differences in fork length showed that EDMs were larger in Coteau Bay than in both Aiktow Creek and Sage Bay (ANOVA with covariate in NWP 1998, not shown). Any further details or confirmation of this will need more data.

In conclusion, Coteau Bay EDMs are larger than Aiktow Creek and (maybe) Sage Bay, and similar to the other sites.

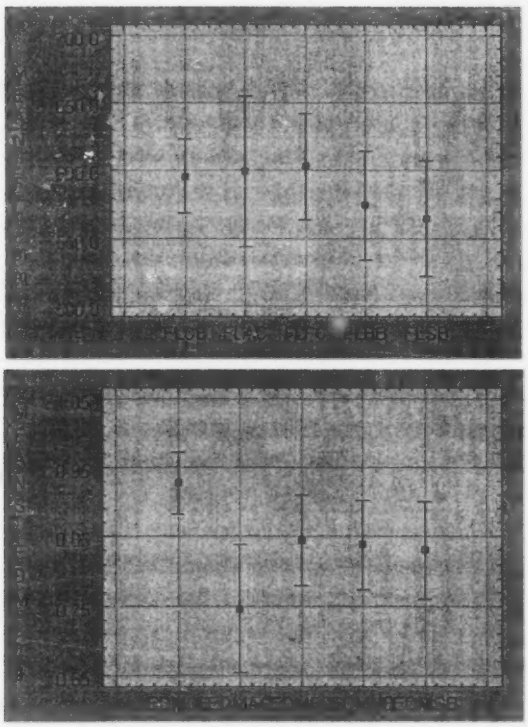

Figure 5. Comparisons of fork length (upper) and EDMs (lower), by site. Means and 95% confidence limits are shown. Bottom panel bars are in the same order (CB, AC, SC, HB, SB) as the upper. CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.

The overall relationship of EDM to fork length of walleye at several sites in 2002 was negligible:

EDM (mg) = 0.90903 - 0.000072 fork length (mm)

$n = 108$, $r^2 = 0.00017$

The slope was not statistically different from zero due to the large variability.

Using $\log_e$-transformations of length of walleye in 2002:

EDM (mg) = 1.04910 - 0.028625 loge of Fork length (mm)

$n = 108$, $r^2 = 0.0008$

The slope was again negative, but not statistically different from zero.

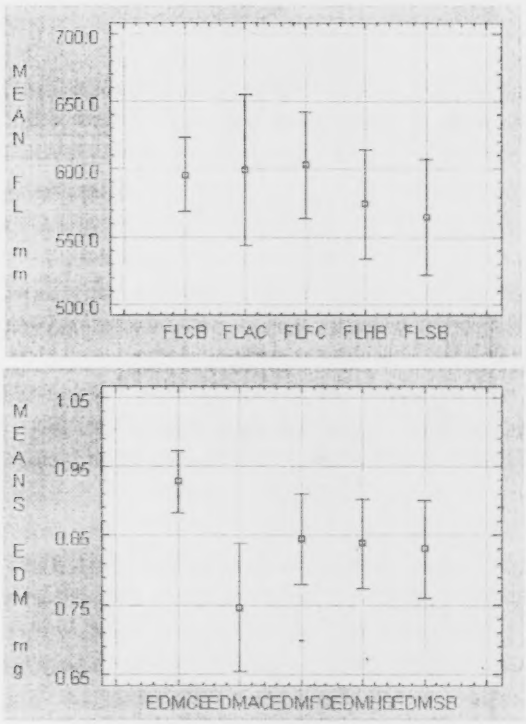

Figure 5. Comparisons of fork length (upper) and EDMs (lower), by site. Means and 95% confidence limits are shown. Bottom panel bars are in the same order (CB, AC, SC, HB, SB) as the upper. CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.

The overall relationship of EDM to fork length of walleye at several sites in 2002 was negligible:

EDM (mg) = 0.90903 - 0.000072 fork length (mm)

n = 108, r^2 = 0.00017

The slope was not statistically different from zero due to the large variability.

Using $\log_e$-transformations of length of walleye in 2002:

EDM (mg) = 1.04910 - 0.028625 $\log_e$ of Fork length (mm)

n = 108, r^2 = 0.0008

The slope was again negative, but not statistically different from zero.

Table 5. Differences in fork lengths and egg dry mass between sites, by ANOVA.

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-Value
Fork Lengths (mm)					
Between-sites	21372	4	5343	0.71	0.5876
Within-sites	776255	103	7536		
Total (corrected)	797628	107			
Egg Dry Mass (mg)					
Between-sites	0.350	4	0.08740	4.21000	0.00330
Within-sites	2.157	104	0.02074		
Total (corrected)	2.507	108			

These slopes and r-square values for 2002 using our modified methods were very close to those obtained in the 1997 survey of Lake Diefenbaker, which established the original method (Johnston pers. comm. 1998):

EDM (mg) = coeff a - 0.01 $\log_e$ of Fork length (mm)

$n = 40$, $r^2 = 0.00$

The negative slope means that larger females tend to produce smaller eggs, although there is very little trend at all. This occurs in a few of the walleye lakes studied (Johnston and Leggett 2002).

For the record, several million fry have been marked with tetracycline and stocked directly into Coteau Bay since 2000:

Year	Marked	Not marked	(Jerry Banks pers comm January 2004)
2000	2.0 million	1.5 million	
2001	3.6 million	none	
2002	3.5 million	1.7 million	
2003	3.6 million	0.4 million	

Several small samples of walleye have been examined to date, although most are ages 3 to 6 and too old to have been marked (Carol Schurr pers comm).

DISCUSSION

This survey was intended as a comparison to 1997 data from Coteau Bay (Johnston pers. comm., Johnston and Leggett 2002) and a baseline for other spawning sites in Lake Diefenbaker. Initially, our results looked unusual and we thought that our field conditions or modified methods were unsuitable.

Regressions of EDM in 2002 showed much lower correlations with fish length than in other studies (r^2 = 0.47 to 0.51 in Johnston 1997). About 9 of 34 populations in North America had negative slopes for $\log_e$ fork lengths (Johnston and Leggett 2002). Further, the tendency to heavier eggs in bigger females was stronger at the extremes of the walleye range, which included populations in NWT, SK, and MB and in the southern USA. For some reason, eggs in Lake Diefenbaker walleye are unusual because they do not vary with female size, or may even tend to be smaller in bigger females.

In general, predicted egg sizes for a "standard size" female vary more between populations than year to year within a population. Coefficients of variation are typically 2 to 5% (Johnston and Leggett 2002), which is relatively precise and should provide good detection of changes.

In wild populations, egg collection for EDM is more feasible but for hatchery monitoring, the equivalent 'fry dry mass' (FDM) would be suitable and easier. FDM is strongly correlated with EDM (about r^2 = 0.94 in 28 batches of eggs hatched by Johnston 1997). Both EDM and FDM could be done for two years to establish a baseline. Collecting about 15 to 30 fry from early, mid, and late hatch dates at the hatchery should suffice. FDM may also better reflect the physiological quality of eggs since size, oil content, lipid forms, and energy are important.

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STRESS AND DISEASE

INTRODUCTION

Long-term hatchery operations have occasionally observed changes in the health of spawning fish, such as symptoms of disease or handling. These would have serious implications for both walleye populations and hatchery programs. There are many ideas for monitoring diseases in wild populations, usually related to contamination by chemicals and sometimes requiring complete external examinations and full autopsies (Goede and Barton 1990).

Previous surveys in Lake Diefenbaker have shown a moderate prevalence of some tumours in older walleye (Cam Portt pers comm). Since the lake is considered to be relatively uncontaminated, we needed some data on the kinds of diseases in walleye and other species.

We also needed an indication of whether handling stress (catching, penning, collecting eggs or sperm, measuring, and tagging) of spawning walleye caused lasting symptoms. This would allow comparisons to other sites and provide a baseline for future Coteau Bay monitoring.

We used the presence and severity of visual signs of the virus 'lymphocystis' (an iridovirus) as an index of general stress in Lake Diefenbaker walleye. Lymphocystis looks like "warts" on the skin or fins due to extreme enlargement of dermal cells or connective tissue (Ott 1994). Symptoms can increase when fish are stressed by natural conditions (e.g. spawning) or by handling (e.g. hatchery operations). It can be common on walleye during spawning, then usually recedes in warmer weather. It has been considered non-fatal to fish since the 1960s, since several earlier tagging studies showed no effects. However, one study of 12,000 walleye showed it caused some mortality, since relatively fewer infected walleye returned the next year than uninfected fish (Margenau et al. 1988). It can be a concern to anglers but does not pass to humans, especially if fish are cleaned and cooked properly (Ott 1994, Kevin Murphy pers comm).

METHODS

Walleye were examined at arms-length for lymphocystis using visual charts to standardize readings among crews and over time. The three categories were: "None", "Mild" (up to 2 or 3 small areas, less than the diameter of a pencil), and "Severe" (several sites or large areas or touching any part of the eye, mouth, or gills).

We did not attempt to distinguish lymphocystis from 'walleye dermal sarcoma' (WDS), although the granular look of lymphocystis seems clearly different from the smoother look of WDS (Getchell et al. 2000). Any changes in either virus would be of interest, and experts in this topic are available in Saskatchewan as needed (Gary Wobeser pers comm).

We planned to examine enough fish for lymphocystis to detect a doubling of incidence. For a baseline of 1 % infection, this requires observations of 524 walleye initially and 524 in future surveys. For a baseline of 3 % infection, 172 fish are required each time (from Sample-size module in NWP 1998 with power = 80% and alpha error = 20%). We intended to observe specimens randomly in early, middle, and late spawning days. In practice, it was usually simpler to examine all walleye.

At Coteau Bay, recording symptoms for all recaptured walleye with tags (from 1998 to 2000 operations) provided an indication of previous and lingering stress. These walleye had already been handled 1 to 3 times.

At all sites, tag sores or ulcers were recorded for each type of tag and the severity was noted. "None" means healed even if the original injection spot can be detected, "Mild" is smaller than a pencil diameter, and "Severe" is larger than pencil or deeper than 3 mm (1/8") or raw or "weeping" wound.

Occasional specimens were collected for necropsy if visual symptoms of disease, deformity, or oddity were observed. These included fin erosion, skin ulcers, visible tumours, deformed skeletons, and eye disorders. One exception was a large female that was apparently blind in both eyes, seen in Hitchcock Bay in 2001 and released out of empathy for her ability to survive (Tom Maher and Kevin Murphy pers comm). Whole fish were frozen, after the liver, one eye, one gill, and any diseased parts were excised and preserved in 10 % histology-grade formalin. These were submitted to pathologists at the Western College of Veterinary Medicine in Saskatoon (Dr. Gary Wobeser and Dr. Trent Bollinger).

RESULTS

At least 6,000 walleye were examined for lymphocystis from 2001 to 2003:
Coteau Bay 4,600; Aiktow & Summit Creeks 1,620; Hitchcock & Sage Bays 720.
At Coteau Bay, most walleye were examined in 2003 by EcoRegion staff assisting with hatchery operations (Sandra Jewel pers comm).

Preliminary results showed lymphocystis occurred in about 10 % of Coteau Bay walleye and 2 % of walleye at other sites in 2001 (Table 6). The next year, rates were lower at 8.7 % in Coteau Bay and slightly higher at 3.4 % in Aiktow & Summit and 3.0 % at Hitchcock & Sage. Rates continued to rise at AC & SC and at HB & SB in 2003.

Rates at Coteau Bay were significantly higher than other sites in both 2001 and 2002 (P-value <0.05), but rates were not different between other sites.

Table 6. Rates of lymphocystis presence (% mild or severe) in 2001 and 2002.

	Site [a]			
Year	AC & SC [b]	HB & SB [b]	AC,SC,HB,SB [b]	CB [b]
2001	2.2 (905, 1.9 - 5.6)	2.0 (100, 0.6 - 7.0)	2.2 (1005, 1.4 - 3.3)	~10 [c] (2260, ~9 - 12)
2002	3.4 (639, 2.3 - 5.2)	4.9 (491, 3.3 - 7.2)	4.1 (1130, 3.1 - 5.4)	8.7 (1158, 7.2 - 10.5)
2003	7.9 (76, 3.7 - 16.2)	12.2 (131, 7.7 - 18.9)	10.6 (207, 7.1 - 15.6)	7.0 [d] (1187, 5.7 - 8.6)
Females:				
2001	1.2 (495, 0.6 - 2.6)	1.5 (65, 0.3 - 8.2)	1.2 (560, 0.6 - 2.6)	3.5 (1152, 2.6 - 4.7)
2002	3.4 (358, 1.9 - 5.8)	5.0 (240, 2.9 - 8.5)	4.0 (598, 2.7 - 5.9)	7.9 (706, 6.2 - 10.2)
Males:				
2001	3.4 (409, 2.0 - 5.7)	2.9 (35, 0.5 - 14.5)	3.2 (443, 2.1 - 5.5)	8.5 (1108, 7.0 - 10.3)
2002	3.6 (281, 2.0 - 6.4)	4.8 (251, 2.8 - 8.2)	4.1 (532, 2.8 - 6.2)	9.9 (453, 7.5 - 13.0)

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.
[b] Number of fish observed and 95% confidence limits are shown in parentheses.
[c] Approximation, based on 12.7 % in recorded individuals and 5.9 % if blank data are all 'N'
[d] Sex was not recorded for the majority of observations.

To assess the effects of handling (by hatchery and assessment crews), we analyzed sub-groups of walleye based sex, size, and an index of tagging history. 'History' was based on the presumed severity of previous tagging multiplied by time elapsed since tagging. Some kinds of tags seemed inherently more likely to allow the entry or proliferation of viruses:

— tags that were injected but protruded did not usually allow skin to heal and were rated severity 2, including metal gill-cover tags from 1998 (denoted 'MT'), and T-bar tags with serial numbers (TSN) or batch colours (TCO) from 2001 (see 'Abundance and Mixing' for details of tags).

— tags that typically allowed skin to heal over were rated severity 1, including punched holes in the second dorsal fin in 1998 and 2000 (DP), visible implant elastomer (VIE) on lower jaws from 2001 to 2003, and PIT tags implanted into cheeks from 2001 to 2003.

Differences in two variations of time elapsed were slight. 'Straight' used a time-severity of 4 if tagged one year previously (such as fish from 2001 being observed in 2002), 3 if two years, 2 if three years, and 1 if four years). 'Decay' used fractions of 1/1, 1/2, 1/3, and 1/4, respectively. Combinations of tag and time factors were limited by the use of different tags in different years, so both classified available data into similar sub-groups.

Results for sub-groups of fish showed that females with 'high' index had rates of 8.0 % in AC & SC and 14.9 % in CB (Table 7). These were substantially higher than females with 'none' or 'medium' index, which showed about 3 % in AC & SC and 6 % in CB. At a few sites, the differences between 'high' and 'none' or 'low' females were statistically significant (e.g. 21.0 *versus* 3.7 % in HB & SB). Females with 'none' were considered to be background at 2.9 to 3.7 %.

Rates were statistically similar for females with 'high' index at all sites, since some of these fish moved from Coteau Bay and all others were caught and tagged similarly (although not penned except at Coteau Bay)(Figure 6). Rates were also similar among females with 'none' or 'low' index (shown as LO in Figure 6).

Rates were generally higher for females of 500 to 600 mm long, although confidence limits were wider due to fewer specimens.'High' and 'medium' females had rates of 14.3 to 20.0 % (Table 7). These rates were not statistically higher than for all females, as shown by overlaps in their confidence limits.

About 46 walleye in 6 lots were submitted for necropsy in 2001 and 2002:
Coteau Bay 29 specimens; Aiktow & Summit Creeks 14; Hitchcock & Sage Bays 3.

The diagnoses reported to date include:

Coteau Bay 2001 (12 walleye)
— active lymphocystis in 4 fish and WDS (walleye dermal sarcoma)-compatible neoplasm "that may be regressing" in 1 fish;
— chronic inflammation caused by degeneration of lymphocystis in cells in 1 fish;
— lymphocystis that seems to be "resolving" in 1 fish;
— perforation of 5 mm from the metal tags used in 1998;
— hyperemia in caudal area, yellow plaque behind eye, and 1 cm ulceration of gill cover;

Aiktow and Summit Creeks (3 walleye)
— lymphocystis in 2 fish.

The degeneration or regression of lymphocystis had not been observed previously in walleye in Saskatchewan (Gary Wobeser pers comm).

Table 7. Rates of lymphocystis presence (% mild or severe) in sub-groups of female walleye, 2002.

Sex and History	Site [a]			
	AC & SC [b]	HB & SB [b]	AC, SC, HB, SB [b]	CB [b]
Females, all sizes				
All	3.2 (1.9 - 5.6)	5.0 (2.9 - 8.5)	3.9 (2.6 - 5.8)	8.0 (6.2 - 10.2)
High	8.0 (2.2 - 25.0)	21.0 (8.5 - 43.3)	13.6 (6.4 - 26.7)	14.9 (10.0 - 21.5)
Medium	...	...	...	6.0 (2.6 - 13.2)
Low	N/Ap	N/Ap	N/Ap	6.1 (4.3 - 8.7)
None	2.9 (1.6 - 5.2)	3.7 (1.9 - 7.1)	3.2 (2.0 - 5.0)	N/Ap
Females, 501 to 600 mm long				
All	8.3 (4.6 - 14.5)	5.8 (2.5 - 12.9)	7.2 (4.4 - 11.6)	10.3 (6.9 - 14.9)
High	20.0 (5.7 - 51.0)	...	18.8 (6.6 - 43.0)	14.3 (7.1 - 26.7)
Medium	...	...	...	17.6 (6.2 - 41.0)
Low	N/Ap	N/Ap	N/Ap	8.2 (4.9 - 13.6)
None	7.2 (3.7 - 13.6)	5.1 (2.0 - 12.5)	6.4 (3.7 - 10.8)	N/Ap

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.
[b] 95% confidence limits are in parentheses; only sub-groups of 10 or more fish are shown.

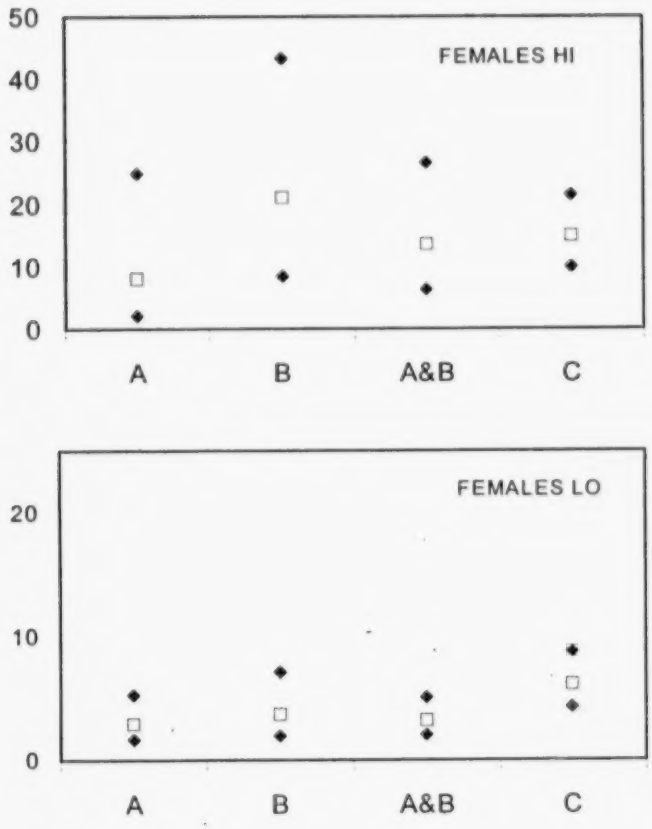

Figure 6. Rates of lymphocystis in female walleye for different areas and handling effects, 2002. Open symbols show averages; solid symbols are upper and lower 95% confidence limits. "HI' denotes those females with a high index and "LO" those with a low index, as described in text. Note the change of scale for lower percentages shown in the LO sub-group. Area A includes Aiktow and Summit Creeks, area B includes HB Hitchcock and Sage Bays, and area C is Coteau Bay.

DISCUSSION

Lymphocystis incidence was part of a disease index used to assess any impacts of hatchery operations over a decade on Crean-Heart Lakes. Lymphocystis was present in only 1 % of spawners, while WDS (walleye dermal sarcoma) and others occurred in almost 10 % (Mathias et al 1985).

Other populations can show Lymphocystis ranging from low to very high:
— 18 % of 12,000 walleye among spawners in St. Louis River, WI (Margenau et al. 1988);
— 1 to 5 % during spawning season in Oneida Lake, NY (Walker 1958 cited in Colby et al. 1979);
— increasing from 17 to 30 % during the spawning period in Nipigon River, ON (Ryder 1961 cited in Colby et al. 1979).

Severe symptoms may affect swimming, vision, or feeding (Ott 1994). Transmission of the virus is primarily by contact with an infected fish, but it does not seem to spread orally or via eggs or sperm (Ott 1994). It will also infect nearby fish in several days without direct contact (Bowser et al. 1999).

There were suggestions in the 1970s that handling and tagging tend to spread the disease (Colby et al. 1979). There are also populations with naturally high background rates, as was observed in the first year of hatchery operations at Bad Carrot River, one of the former "spawn camp" locations (Jerry Banks pers comm 2002).

When incidence rates at Diefenbaker became known by 2002, FCS staff began to count and release walleye with severe lymphocystis directly from trap-nets. This is probably a good idea since it minimizes transmission during penning, but it prevented further analysis of the effects of specific tags in 2003. Yet how do you argue with reasonable actions when enough data had likely been collected?

Older female walleye from Coteau Bay were used as controls in a recent study of liver tumours in Great Lakes walleye. About 24% of 25 females from Coteau Bay had the tumours, described as "expansive but non-aggressive populations of phenotypically altered hepatocytes that are greater than 5 mm in diameter". One of these females also had hepatocellular and pancreatic neoplasms that had not been seen elsewhere (Cam Portt pers comm July 1999). Our necropsies of Lake Diefenbaker walleye to 2003 show typical wild population symptoms.

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SIZES AND AGES

INTRODUCTION

We needed to compare size and age compositions of representative spawning populations around the lake. Ages were collected at Coteau Bay in 2001 and at all sites in 2002. This provided an update of the ageing data from 1995, which were used in Jensen and Wallace (2001). The previous specimens were caught in open-lake area in summer.

Dorsal spines can be collected and fish released without obvious mortality, and spines are reliable for ageing (Borkholder and Edwards 2001).

Age materials were also used in analysis of growth patterns in walleye to address concerns about impacts of escaped rainbow trout. Any changes in walleye growth would presumably be related to competition from rainbow trout (see Growth).

METHODS

FCS and assessment crews caught walleye with trap-nets. Sub-samples of walleye at Coteau Bay and all walleye at other sites were examined. Fork lengths were recorded and tags were applied. Occasionally round weights were recorded, separately for unripe ('green') and ripe walleye and 'spawned out' females.

Samples of ageing materials were collected, usually from 10 fish per 5-cm length interval. We needed a cross-section of walleye lengths by sex, and aimed for 100 each week for each site. Two or three spines from the front of the first "spiny" dorsal fin were sheared. Bone-cutters allowed shearing within 1/8 inch of the base, even into the notch if necessary. This was to avoid losing early annuli and an attempt to standardize annular measurements (see Growth).

Age materials were labelled, dried and stored several months. Routine methods of ageing included embedding spines in epoxy, sectioning them with diamond-grit saw, and interpreting annuli (Carol Schurr pers comm, modified from Musker 1985).

Fork-length compositions were tallied for males and females separately. These were then combined with separate 'age-length keys' of aged fish to obtain total age compositions. Annual mortality rates were calculated from the slope of log (number of fish at each age) against age in the usual manner (that is, instantaneous mortality Z = Ln(-Slope) and annual mortality A = 1 - Exp(-Z), Ricker 1975). Mortality rates are quoted from the age of apparent full recruitment as spawners to the oldest specimen.

RESULTS

About 5,700 walleye lengths were recorded at the sites over three years. Over 2,000 of these were from Coteau Bay due to easy access to thousands of spawners. In 2003, numbers of fish measured were quite low in most areas due to poor catches.

Female walleye averaged from 520 to 600 mm at various sites and years. Males averaged 440 to 480 mm (except about 400 mm in Hamilton Flats), usually about 100 mm shorter than females (Table 8).

In general, walleye were significantly longer at Aiktow and Summit Creeks other areas in most years. The other areas were similar, although males in Hamilton Flats were smaller in 2003:

Year	Females	Males
2001	AC&SC > HB&SB > CB	AC&SC > HB&SB > CB
2002	AC&SC > HB&SB ~ CB	AC&SC > HB&SB ~ CB
2003	AC&SC > HB&SB ~ HF	AC&SC > HB&SB > HF

The symbol '>' means greater than and '~' means approximately equal median lengths, Mann-Whitney test at p=0.05. Statistically, these comparisons were not strictly 'transitive' but we showed results from larger sample sizes when the results differed. Therefore, when AC&SC was greater than HB&SB which was itself equal to CB, then AC&SC was also significantly greater than CB. The low numbers of walleye in 2003 reduced the ability of some statistical comparisons to detect any differences that may have been present.

Sizes were usually steady from year to year at each area:

Area	Females	Males
AC&SC	2001 ~ 2002 ~ 2003	2001 > 2002 ~ 2003
HB&SB	2001 ~ 2002 > 2003	2001 ~ 2002 ~ 2003
CB	2001 < 2002	2001 > 2002.

Coteau Bay walleye were not measured randomly in 2003, so are not shown.

Representative size compositions for 2002 showed the differences observed between areas and sexes (Figure 7). The major difference was that females were substantially longer than males, as is typical for walleye. We assumed the differences between areas and years were due to the small numbers measured in some cases or to natural fluctuations (such as the passage of year-classes).

Table 8. Summary of fork lengths of walleye measured, 2001 to 2003.

Year	Site [a]								
	AC & SC			HB & SB			CB		
	Nos	Avg	(Min - Max)	Nos	Avg	(Min - Max)	Nos	Avg	(Min - Max)
Females									
2001	485	602	(423 - 786)	65	590	(446 - 798)	1144	554	(361 - 812)
2002	370	612	(424 - 787)	243	571	(394 - 778)	706	569	(412 -770)
2003	49	603	(474 - 770)	42	518	(350 - 745)	...	...	... [b]
						Hamilton Flats [c]:	35	550	(395 - 748)
Males									
2001	404	481	(363 - 675)	34	456	(350 - 612)	1105	447	(288 - 650)
2002	281	460	(283 - 605)	251	436	(321 - 619)	454	441	(328 - 626)
2003	52	467	(348 - 600)	89	438	(342 - 525)	...	...	... [b]
						Hamilton Flats [c]:	74	402	(324 -570)

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.
[b] Only previously tagged fish were measured, so the samples are not comparable.
[c] Fished only in 2003.

About 1,000 walleye were aged, using dorsal spines from 200 or more fish at each site.

Females first showed up among spawners at age 5, but very few. Full recruitment to spawning occurred at age 6 and maximum ages reached were 17 or 18 years (and one specimen at 22 in Coteau Bay). Annual morality rates varied from 13 to 20% (Table 9).

Males showed up at age 4, recruited fully at age 5, and reached maximum ages of 11 to 19 years. Mortality rates were higher than females (as expected) and varied considerably from 27 to 41%. For some reason, Aiktow Creek and Summit Creek males had the highest mortality rates at 41 and 35 %, respectively.

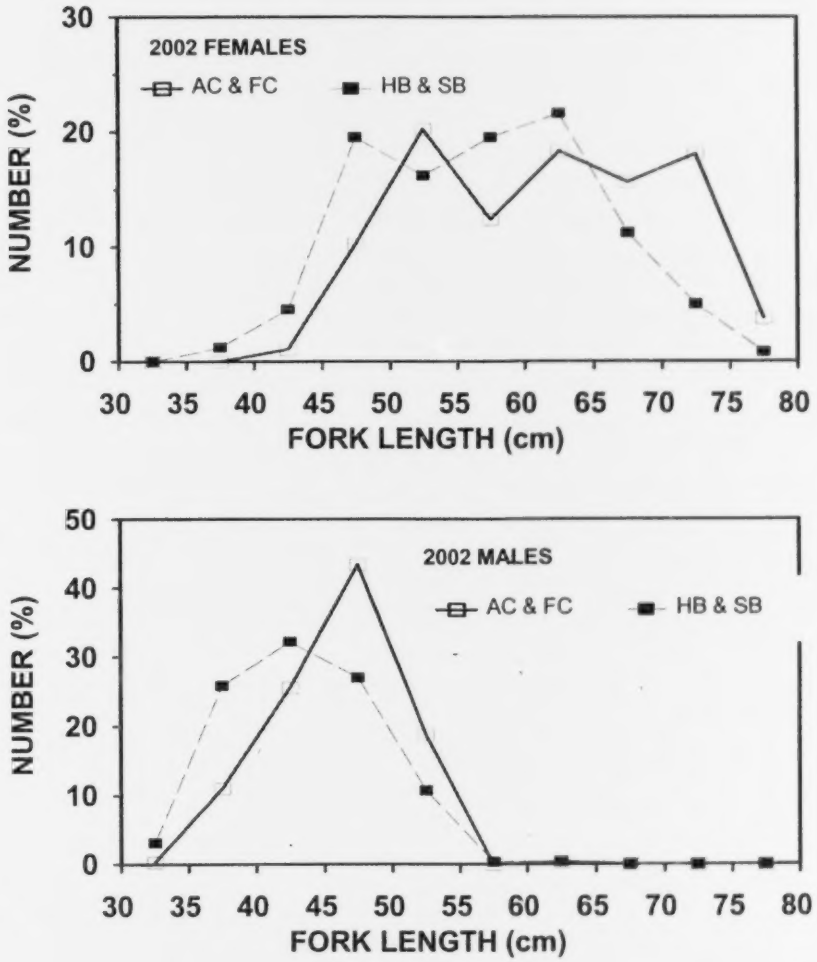

Figure 7. Size compositions of walleye at two representative areas, 2002. Both females and males were significantly longer in AC&SC than HB&SB, which were similar to those in CB (see text). Site CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, and SB Sage Bay.

In 2003, a few 3rd or 4th dorsal spines were also collected from recaptured fish that had been aged in 2002. This will allow for partial validation of ageing by dorsal spines, by checking for the expected one additional year of added age.

Generally, female walleye aged 8 or 9 (and maybe 10) were scarcer than expected, and those aged 11 or 12 were more abundant (Figure 8). This implies that conditions in spawning years 1993 and 1994 were relatively poor and in 1990 were relatively good. Male walleye show only that age 8 (1994) is weak, and maybe ages 9 or 10.

Table 9. Summary of ages and annual mortality rates, several sites in 2002.

	Site [a]				
Year	AC & SC		HB & SB		CB
Females 2002					
Number aged	86 [b]		141		148
Mortality (over Ages)	15% (6 - 18)	19% (6 - 18)	20% (6 - 19)	13% (6 - 19)	19% (6 - 20)
Males 2002					
Number aged	98		167		80
Mortality (over Ages)	41% (5 - 11)	35% (5 - 12)	28% (5 - 16)	29% (5 - 14)	27% (5 - 19)

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, and SB Sage Bay.
[b] Some length and age combinations were not sampled, so age compositions may be slightly less reliable.

There were differences between areas: Hitchcock Bay female year-classes fluctuate more than Sage Bay; Coteau Bay females aged 7 were unusually abundant compared to other areas. These may have been real differences since some sites were more exposed to spring wind conditions or had more runoff prior to recent droughts.

Other reasons for results differing between sites included low numbers of some length and age data (such as Aiktow and Summit Creeks). Errors in reading of ages will be apparent visually but maybe not a problem if errors were unbiased (that is, reading ages too old as often as reading them too young). Simulations have shown that errors do not affect analysis of year-classes up to moderately high error rates of 40% (Robinson and Casselman 2000 pers comm). The usual tendency, however, is for more difficulty and some under-ageing with older fish.

Combining age compositions for all sites showed that females aged 6 and 7 each represented about 20 % of catches (Figure 9). The variations in year-class abundance show as fluctuations around the regression line of the declining slope (Ricker 1975). The fluctuations (or 'residuals') are positive for year-classes which are more abundant than expected, and negative for less abundant.

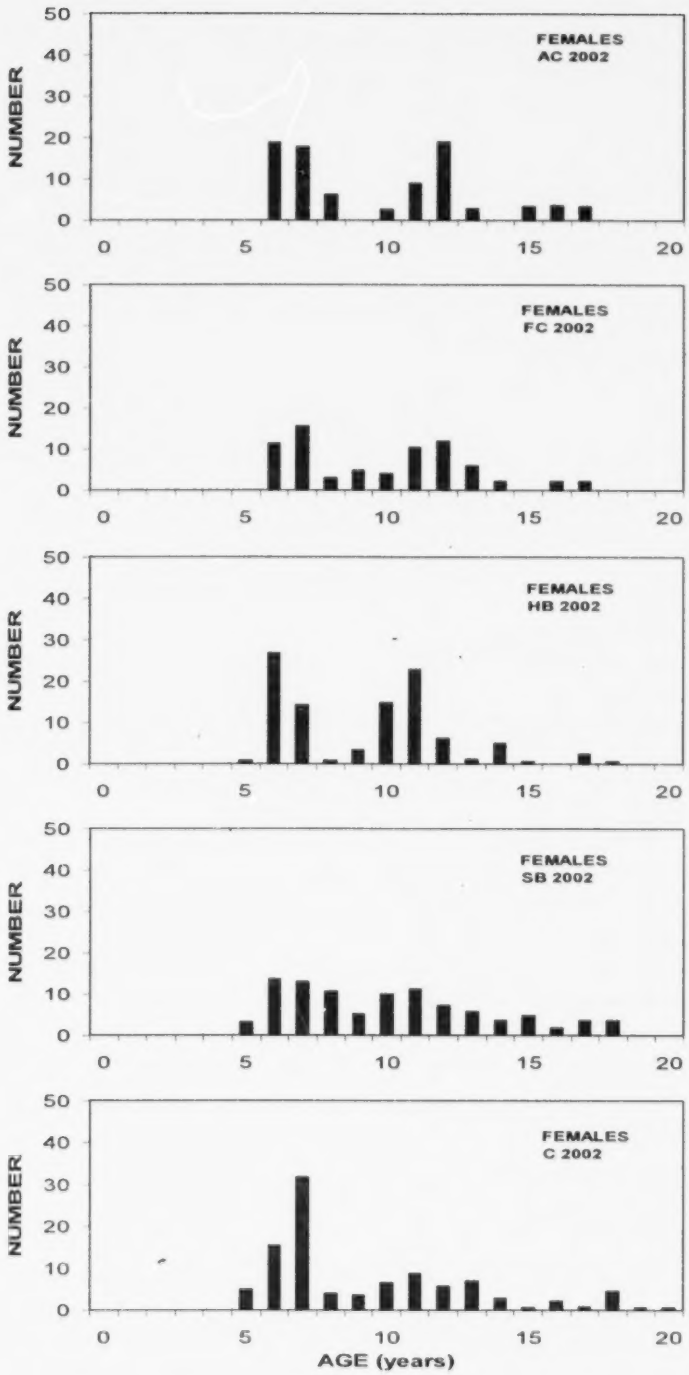

Figure 8. Age compositions of walleye at several sites, 2002. Females are shown.

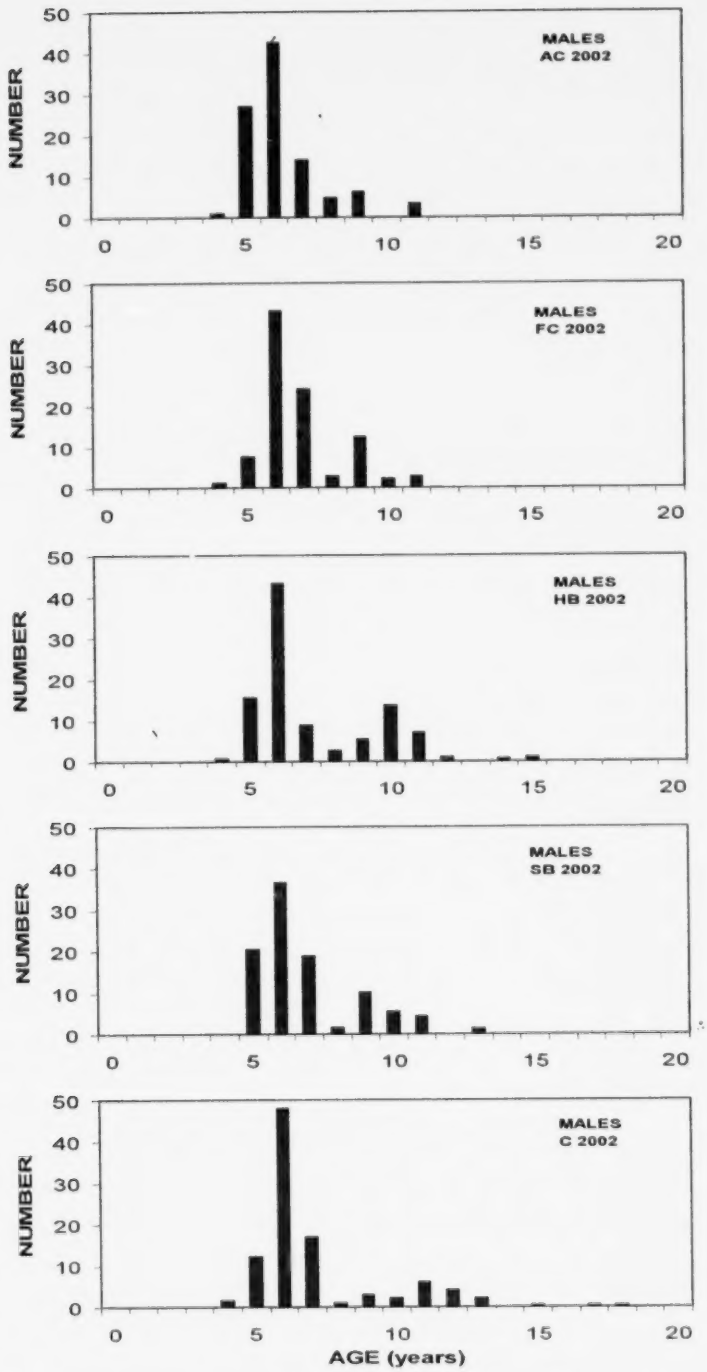

Figure 8 cont'd. Age compositions of walleye at several sites, 2002. Males are shown.

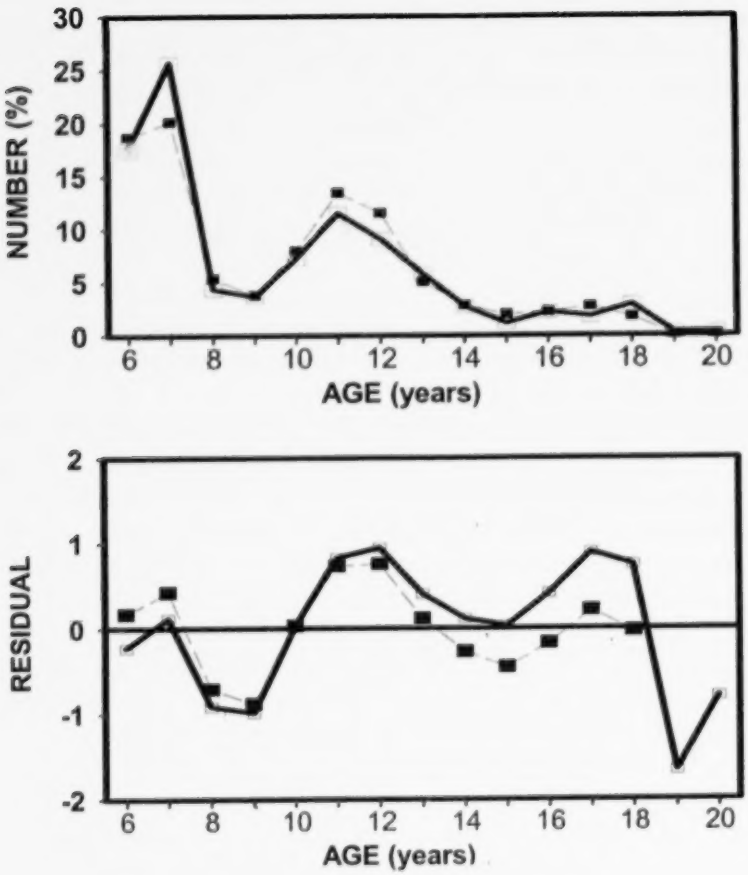

Figure 9. Age composition and year-class strengths of female walleye, all sites 2002.
UPPER: Numbers are weighted by catches at each site (solid line and open boxes), and unweighted by catches (dashed line and solid boxes).
LOWER: Residuals from regression of $\log_e$ of numbers versus age. Regressions are unweighted by catches for ages 6 to 20 (solid line and open boxes) and ages 6 to 18 (dashed line and solid boxes).

The regression for ages 6 to 20 was:

Log_e (Number% + 0.01) = 4.817 - 0.2766 Age

$n = 15$, $r^2 = 0.71$

The regression for ages 6 to 18 was:

Log_e (Number% + 0.01) = 3.824 - 0.1782 Age

$n = 13$, $r^2 = 0.66$

The moderate correlations suggested that year-class variations were relatively moderate.

When residuals were plotted against age, they showed that ages 8 and 9 (1993 and 1994) were weak years and ages 11 and 12 (1990 and 1991) were strong years for females (Figure 9). Ages over 15 are uncertain, as fluctuations around regressions up to age 18 and 20 disagree. The analysis further suggested that variations in year-classes were similar from 1987 to 1996 (ages 6 to 15, see RCD index in Isermann et al. 2002).

DISCUSSION

The general patterns observed at our sites are not unusual for walleye populations: female spawners are larger than males, females live longer than males due to lower mortality rates, and year-class abundances fluctuate (Colby et al. 1979).

Differences in size compositions between sites in Lake Diefenbaker are not presently a concern. If the differences increase or fluctuations become larger, that assessment may change. The larger walleye in the Aiktow and Summit area may be due to less fishing than in Coteau Bay and Hitchcock and Sage Bays, although tournament and other angling at the Qu'Appelle Dam may have increased recently (Ron Jensen pers. obs., Al Daly pers. comm.).

The sizes and ages observed are those expected for healthy spawning populations (Colby et al. 1979). Females up to age 18 at Swan Creek (MB) have sustained egg collections for a decade or more (Johnston 1997). Two unexploited lakes at similar latitudes in Manitoba have ages up to 17 and 20 (Home and Wapun lakes in 1979, Mathias et al. 1985).

The present mortality rates are higher than reported for the Coteau Bay population in 1998 to 2000. This is only because we previously used age-length data from lake-wide surveys in 1995 to estimate age compositions and annual mortality (females 13% and males 18% in Jensen and Wallace 2001). Ages were not collected from Coteau Bay during 1998 to 2000.

Year-class abundances showed fluctuations at our sites of about 3-fold. Effects of climate and water conditions on the success of walleye spawning and year-class strengths are well known. Typically, favourable conditions include moderate spring warming, absence of disruptive cold events (such as snowfall) during spawning, steady or rising water-levels during incubation, and predator/prey conditions. Sometimes the suitability of conditions extending into the first summer or longer are important, since that is the period that walleye abundance is typically set (see 'FCS Monitoring').

Weak or strong year classes of walleye tend to correlate with regional climate. The effect may reach from Prince Albert National Park to lakes in west-central Manitoba (Mathias et al. 1985). Others have observed a weak 1993 year-class in several Saskatchewan lakes (Mark Duffy and Kevin Murphy pers. comm. 2003). Unusually poor classes were observed in Minnesota in 1992 and 1993 (Schupp 2000). June temperatures were 2° C below normal due to the eruption of Mount Pinatubo (Philippines) in 1991. The effect may have persisted until 1994 in Saskatchewan, or poor conditions may be due to more regional climatic variations.

Most reports of year-class strength depend on long series of catches by age, sometimes adjusted for seasonal weather or different gears. The use of age compositions was the only method available for Lake Diefenbaker. This method assumes that mortality is the same for all ages and does not change over time (Isermann et al. 2002). It does not adjust for long-term variations in fishing or cumulative effects for older ages. Accordingly, residuals may decline among older ages as strong year-classes are attenuated over time. The lack of this pattern in residuals for ages 6 to 15 in Lake Diefenbaker suggests that young ages are not fluctuating more than older ones due to very high exploitation or extreme variability in conditions.

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GROWTH

INTRODUCTION

In 1999, about 400 thousand rainbow trout escaped from an aquaculture operation near Birsay. Although some were recovered, most remained in the lake — with several consequences. First, anglers saw this as such an opportunity that their activity was picked up in province-wide licences sales and a survey of sport fishing in 2000 (Star-Phoenix 2000, Tanya Johnston pers comm, Fisheries and Oceans 2003).

Second, fisheries biologists saw this as an injection of a non-native species (in numbers about equal to the number of walleye in a lake of this size, from Baccante and Colby 1996). Their concerns about impacts were shared by some anglers (Wayne Phillips pers comm 2001).

Since potential impacts are varied and the most recent fish-population survey on the main lake was 1995, there were few baseline data to assess any impacts. One of the few ideas that seemed feasible was changes in growth patterns in walleye from direct competition for food.

This required a retrospective look at large numbers of females and males of different ages, for separate calendar year & age combinations, to detect changes in annual growth increments from before to after the escape.

Dorsal spines were available from live-release fish, and are reliable for study of growth (Borkholder and Edwards 2001) and perhaps better than otoliths (Campana 1990).

METHODS

We used a digital camera and microscope to photograph cross-sections of dorsal spines that had been aged, analyzed the images using software that recorded x,y positions of each annulus, and used increments as measures of summer growth at particular ages and calendar years.

The microscope was a Wild M3 stereoscope with an ocular removed and various adapters to hold a Sony Mavica FD-83 with a protective lens filter. Images were captured and analyzed:
— images were viewed and selected with 'Print Screen Deluxe' and 'ACDSee' software (American Systems Inc version 4.0b and ACDSystems version 3.1);
— annular locations were located visually and counts checked against predetermined ages;
— image formats were converted, resized, adjusted for brightness & contrast, and saved using ImageJ freeware (NIH version 1.27z at rsb.info.nih.gov/ij);
— x,y co-ordinates were recorded to text-file using PointPicker add-in for ImageJ (by P. Thevenaz at ioasun2.epfl.ch/thevenaz/pointpicker).
The hardware and software was coincidently the same as used for cod by Sinclair et al. (2000).

Annular loci were taken along three axes:
— two series from the focus outwards, along the axis from side to side of the section, within 23 degrees of perpendicular to the 'valley' at the posterior), with the readings averaged;
— one series following the loci of longest increments into the posterior corner (Figure 10).

Various age and calendar combinations were aligned and growth increments examined. Attempts to standardize annular measurements may have been reasonable, but in the end other factors were more of a problem.

RESULTS

Several hundred walleye from 5 to 13 years old were analyzed to cover those ages with reasonably large growth in length (Table 10). Younger walleye may have been useful but were not available, and fish aged 5 or older provided several years of pre-escape growth as a baseline. While the work was extremely tedious, the image tools simplified tasks and provided lasting records (Kirsten Jensen pers comm).

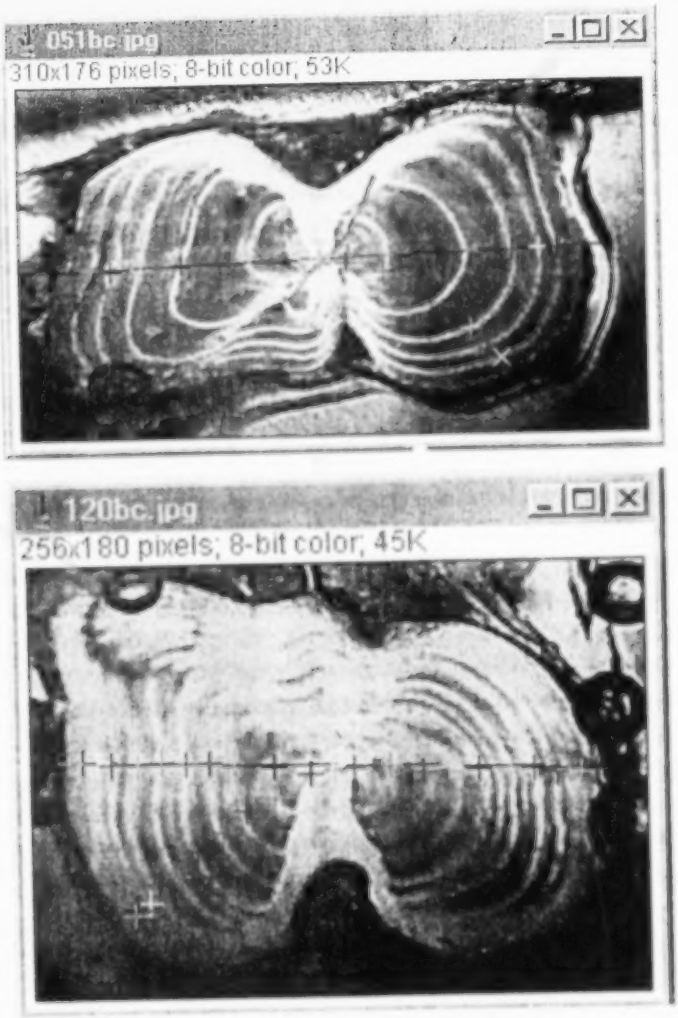
Initially, growth increments showed reasonable confidence bands and seemed suitable — probably better than expected. However, comparisons of growth patterns for different ages revealed a serious problem that was inherent in the fish, and was not resolved.

When several ages-at-capture were compared, they showed large differences in growth during early life (the summers of age-0 to age-3). Female walleye were particularly noticeable (Figure 11), although males showed some effects. The implication was that females caught at age-6 grew much faster at age-0 in the summer of 1995 than age-8 grew at age-0 in 1993, or age-10 grew in 1991.

The size of the differences from age-6 to age-10 was not the problem. They showed variations of 2 to 3-fold in summer growth in the lake, probably well within the range observed for walleye. It was the regularity of the differences that was a concern for our purposes.

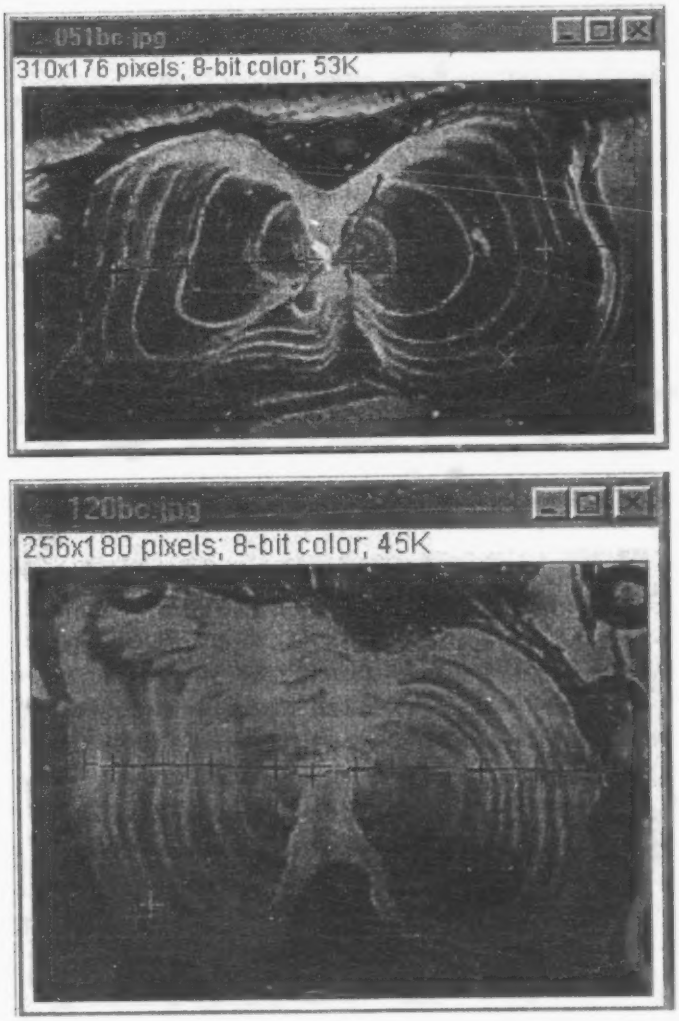
Several explanations were considered:

— Details of magnification and image manipulation were double-checked. Since only 25 and 50 x magnification were used and recorded, and software enlarged photos consistently, these did not appear to be the problem.



	x	y
1st		
	149	87
	139	86
	114	87
	80	89
	60	91
	45	92
	35	91
2nd		
	149	87
	163	85
	184	86
	222	84
	244	84
	258	83
	267	83
3rd		
	149	87
	162	89
	180	94
	204	110
	223	123
	231	131
	238	138

Figure 10. Micro-photo of dorsal spines from two walleye. Crosses on photos show annuli locations along defined axes. X, Y points in the side-bar are an example of the data used for calculations of increments.



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	238	138

Figure 10. Micro-photo of dorsal spines from two walleye. Crosses on photos show annuli locations along defined axes. X, Y points in the side-bar are an example of the data used for calculations of increments.

Table 10. Number of walleye observed and number of dorsal spines (DS) collected for ageing and growth increments, 2001 and 2002.

	Sites [a]			
Number by year	AC & SC	HB & SB	CB	Total
2001				
Number of walleye	835	98	3,263	4,640
Number of DS	0	0	250	250
2002				
Number of walleye	654	569	1,543	2025
Number of DS	185	340	230	755

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.

— Larger walleye may have more of their dorsal spines embedded and less accessible. This seemed unlikely, but was checked by x-raying specimens covering a range of sizes (by Ian Shirley at WCVM using Faxatron and camera capture from x-ray film). Results suggested that all proximal ends of spines lie close to the body surface (Figure 12) and differences are minor.

— Epoxying and sectioning may have been done differently for thinner spines from younger fish than thicker ones from older fish. Field crews at different sites may shear spines differently and/or collect from different sizes of fish. These were also checked and revealed some (minor) differences but no obvious answer (Figure 13).

— Conditions are known to vary by calendar year. Some of the years of poor growth (1991 and 1994) are known to have weak walleye year-classes in Lake Diefenbaker and others (see Sizes & Ages). If low abundance results from poor feeding by young and juveniles, then we saw the effect in our specimens.

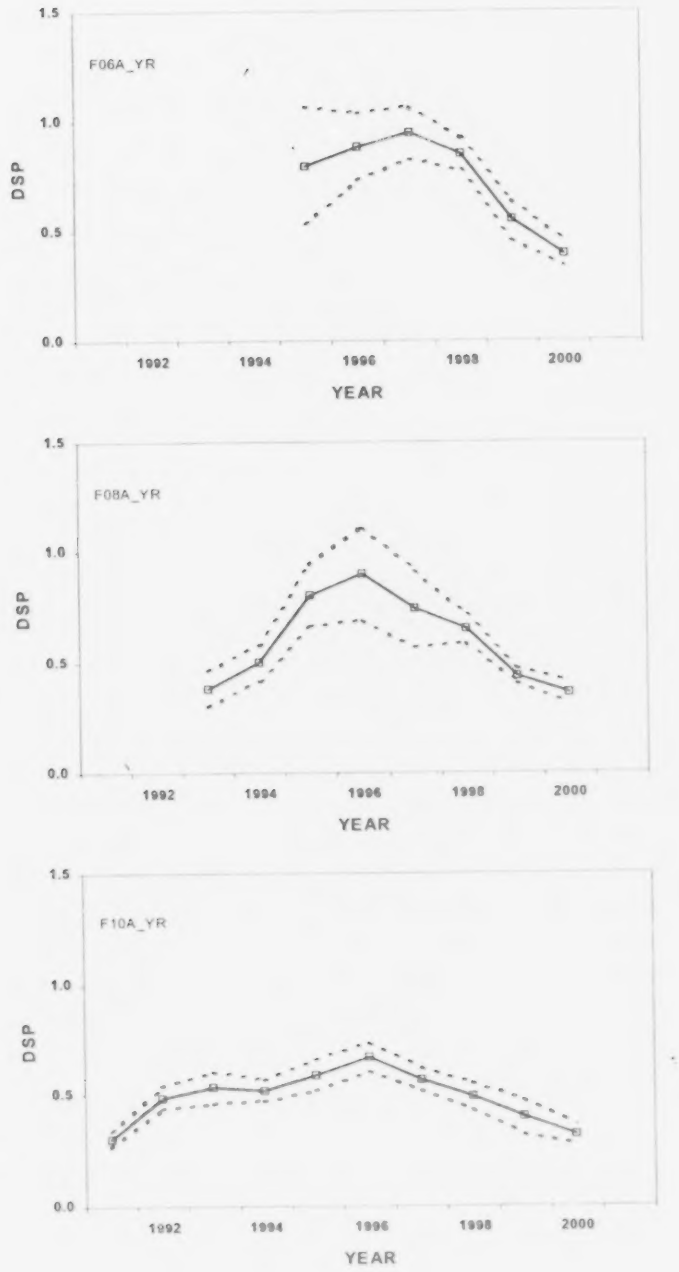

Figure 11. Growth increments in female walleye aged 6 or 8 or 10 at capture. Averages are shown by solid lines; confidence bands are shown as dotted lines.

Figure 12. X-ray of a walleye spiny dorsal fin, showing location and shapes of spines close to the skin. A metal pin 27-mm long was used for scale.

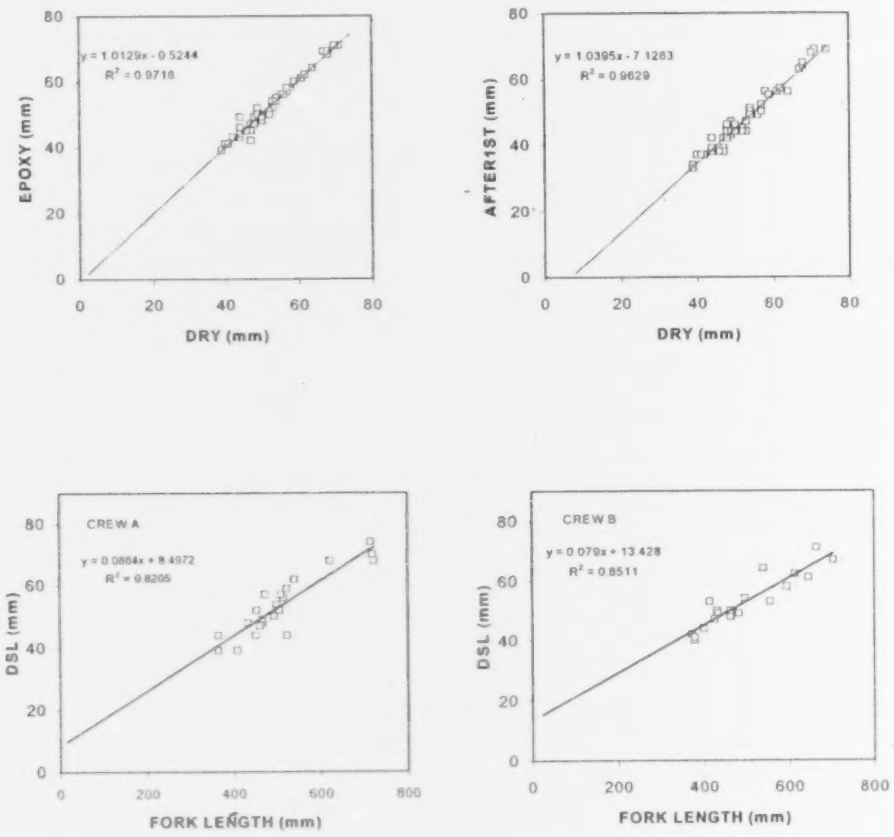

Figure 13. Dorsal spine lengths (DSL) compared for several factors. UPPER: Before embedding and after sectioning. LOWER: For different fish lengths at two sites.

— Faster-growing fish may mature at younger ages, so that female spawners seen at age-6 or 7 were not at all typical. Growth increments in their early summers by age-6 to age-8 spawners were in the upper range of age-9 to 13 fish. Growth by age-6 fish were in the top 2 of 1,000 fish in their first summer and the top 1 in 100 the following. The effect was still obvious for age-8 spawners:

	Growth of different ages of spawners		
Age in summer	Age-6	Age-7	Age-8
0 (young-of-year)	0.002	0.078	0.310
1	0.013	0.055	0.365

This pattern progressed linearly from first to second summer, and from age-6 to 8, so it was difficult to accept as normal fluctuations. The bias seemed very large and was likely associated with maturity, but it may be due to some other factor.

DISCUSSION

The concepts of using annular increments as retrospective 'time-signatures' of growing conditions or for back-calculations of fish sizes at younger ages are well known. This approach was one of the very few suited to our situation. There are typically some concerns about the suitability of various body parts, and the statistical analysis of age & year & interaction terms (Campana 1990, Klumb et al. 2001). Using growth increments measured directly in dorsal spines avoided some complications of converting to fish length, and conversions may only have further obscured the early-growth effect that we observed.

Our sample sizes were designed to provide reasonable numbers of increments for each sex, age, and year, and to cover growth before and after the event. However, the anomalies in ages 6 to 8 meant that reliable growth patterns might only be obtainable from walleye over age 9. This would only cover 'young' growth in calendar years 1993 and earlier, which is too early for the event in 1999. Comparing growth in length at older ages would need to detect changes where increments are small or negligible near the asymptote of length (called L_{inf} in von Bertalaffy curves).

An index of growth to correct for calendar-year effects among our specimens could have been established. However, this would not be particularly useful since there are only one or two years of growth increments available for Lake Diefenbaker. It might suffice for general growth patterns, but would weaken any comparison of increments before and after the escape of rainbow trout.

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ABUNDANCE AND MIXING

INTRODUCTION

The abundances of walleye at spawning sites in this lake are unknown. Anecdotes and investigations by EcoRegional and FCS staff over the years have shown moderate to good numbers in a few areas, such as Gardiner Dam, Qu'Appelle Dam, and Swift Current Creek (Ron Jensen, John Pogorzelec, Hugh Hedger, and Greg Mitchell pers comm). However, some sites are not suitable for effective netting, such as the steep rock wall of Gardiner Dam or deep areas at Swift Current Creek and Sask Landing.

The three areas fished during 2001 to 2003 were chosen to detect mixing among known spawning populations within reasonable distances of each other. Previously observed movements of tagged walleye up the lake following spawning suggest that these sites are well within the range used by Coteau Bay walleye (Jensen and Wallace 2001).

Our design included methods to estimate abundance of individuals during each spawning period and also from year-to-year. During spawning season, fish behave as an 'open' population since they arrive and depart over time. Any analysis needs considerable daily data on tags and recaptures to account for all the variables and to provide confidence limits (Jolly-Seber method). By comparison, year-to-year estimates treat the fish as a 'closed' population (Petersen method in Ricker 1975). One must adjust the numbers of tags initially applied to account for loss of tags and adjust for new spawners among the catch in the second year since they cannot have tags.

The minimum survey needed was three years to cover several areas. Fish would be tagged in 3 areas in year 1, then those 3 sites repeated and 2 more added in year 2, and then the new sites repeated in year 3. Even this gives only 2 years for tagging and 2 for recapturing in each area.

METHODS

We ran simulations of the number of tags needed for daily estimates within each season. Combinations of walleye abundance (usually 5,000), possible efficiency of trap-netting over the time available, and length-of-stay by spawners at the site (from pervious experience at Coteau Bay) were simulated (POPAN5B, Arnason et al. 1998). Many likely scenarios showed they would not provide reliable estimates over two weeks, but some would by day 10 or so.

Planning for year-to-year estimates was simple: (1) populations of 5,000 require at least 150 tags and 150 exams later, since any fewer will under-estimate the true population; (2) populations of 5,000 require 1,000 tagged and 1,000 examinations later to obtain estimates within $\pm$ 10% of the true abundance for research, or 500 and 500 data to be within $\pm$ 25% for management (Robson and Regier 1964). We did not analyze any data with fewer than 7 recaptures since this is known to bias abundance downwards (Ricker 1975).

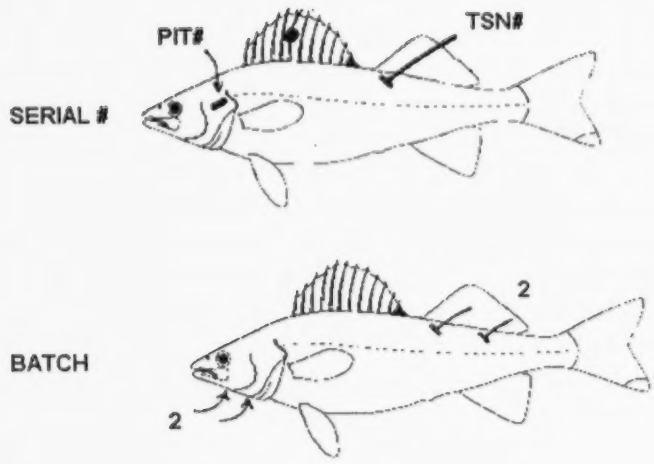

Figure 14. Types and locations of serial-number and batch tags used, 2001 to 2003. Several kinds of serial-number and batch tags are described in the text.

Walleye were tagged with several different types of tags (Figure 14). 'Batch' tags allowed coding of tagging site and year by tag-colour, but did not identify individual fish. 'Serial number' tags had unique identifiers for each fish, as required for within-year abundance. These tags are abbreviated with a '#' as a reminder of this feature. Later, the serial numbers were useful for other purposes, such as comparing lymphocystis in individuals over time, or validating a dorsal-spine age in one year by re-ageing the same fish later. Some tag types were applied as two tags per fish (called double-tagging) to detect tag-loss.

TSN# tags (T-bar tags with a serial number, by Hallprint Australia) were injected forward and inwards into the base of the second dorsal fin. They have a visual ID# that is easily observed: TSN #0000 - 0498 and #1500 - 1599 were used in Coteau Bay in 2001, and #0500 - 0604 at Hitchcock Bay in 2001. These fish also got a permanent punched-hole in the first dorsal fin as a permanent scar to show tag-loss, but this did not work well because similar holes used in 1998 were not clearly placed.

PIT# tags ('passive implant transponder' with serial number, from Biomark USA) were injected downwards and forward into the cheek muscle, usually along the bony margin to minimize chances of accidental ingestion by anglers. PIT# tags require a scanner, and occasionally storage of ID# in memory was not turned on or not working. Hand-written records of full 10-character ID# had some errors and records of abbreviated 5-character IDs were not always unique.

Batch TCO tags (T-bars in several colours) were injected into the second dorsal fin base. They were applied as double-tags: yellow at Aiktow and Summit Creeks, blue at Hitchcock and Sage Bays, and green at Coteau Bay. Large numbers of green tags were applied to detect movement from Coteau Bay into other areas, since limited numbers of tagged fish from the other sites might not be recaptured. If "homing" was particularly strong, we may have had to assume that wandering was similar among sites.

VIE tags ('visible implant elastomer' by NWT USA) were injected as double-tags under the whitish skin of a flat bone of the gill-cover (pre-opercle or sub-opercle along the side, rather than underneath as shown in Figure 14.). Crews tried to inject a small bulb of elastomer or to undulate the filament and to wipe of any external trail to maximize retention (NWT 2001). In 2002, colours were two green at Coteau Bay and two orange at Hitchcock and Sage Bays. In 2003, three of the same colours were used at these sites, and three red at the new site Hamilton Flats.

As anglers and staff noticed and became concerned about tag sores from some types, and data on tag-loss became available, the tag types changed in 2002. Tags that were injected but have trailing filaments were abandoned for ones that heal over, such as PIT# and VIE colours.

At most sites, all walleye caught were counted and tagged and immediately released near the trap-nets, although some were moved from 100 to 500 m away to allow better mixing. The exception was Coteau Bay, where only sub-samples of the numerous walleye were tagged and released at the holding pens, typically 1 km or more from any trap-nets.

Daily estimates of abundance were based on 'capture histories' showing the initial tagging and each recapture by day for individually identifiable fish. We used a Jolly-Seber method that allowed for arrivals and departures by spawners and varying catch rates over time (Model A version of Pollock et al. 1990).

Year-to-year estimates of abundance make several assumptions, including: abundance does not change (for example, by addition of recruits), mortality is the same for tagged and untagged fish, all spawners have the same chance of being caught, tagging does not affect those chances, tags are not lost, and all recaptures are observed. We used the Petersen method modified by Chapman for our 'sampling with replacement' situation, with confidence limits based on the number of recaptures (Appendix II in Ricker 1975).

RESULTS

Different tag types were sometimes used for different sizes of fish. Differences were minor for TCO and PIT# tags in females at Aiktow and Summit Creeks and Coteau Bay. However, TSN# tags were applied preferentially to longer females at Coteau Bay (Figure 15). Also, numerous small males received the cheap and easy TCO tags.

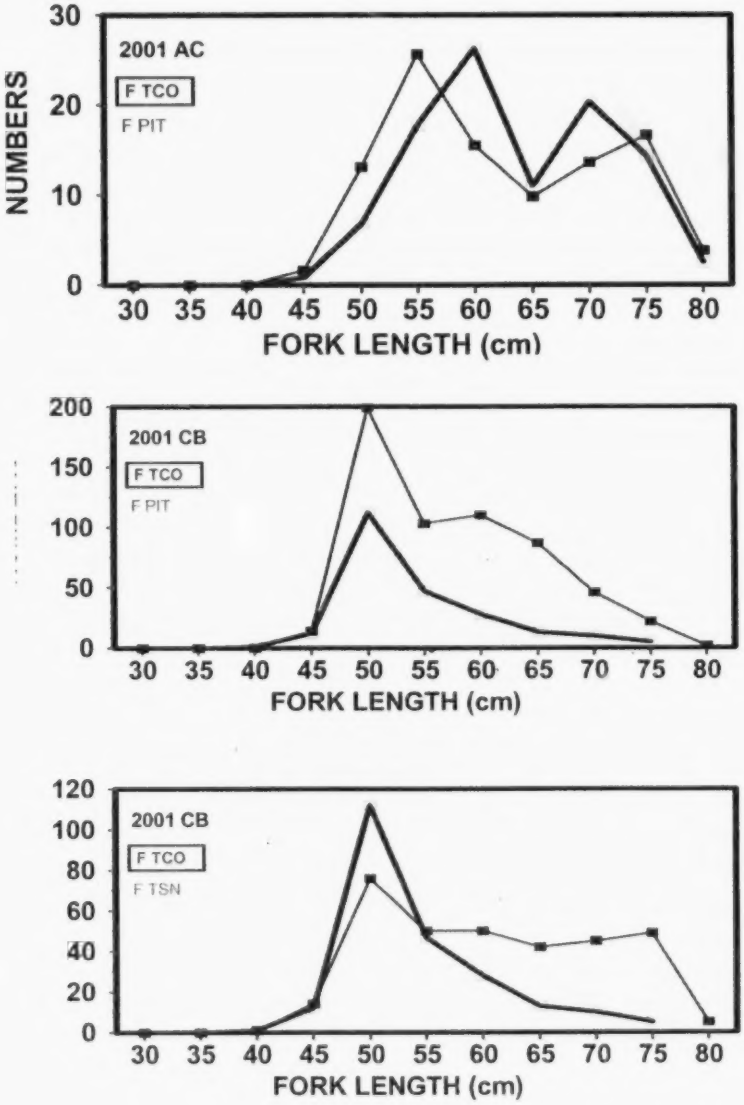

Figure 15. Sizes of female walleye with three types of tags applied, at sites AC & SC and CB, 2001. TCO tags are shown as solid lines with open box symbols; PIT# and TSN# tags are lighter lines with solid box symbols. Site CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.

Analysis of daily mark-recaptures during 2001 provided some estimates of abundance by day. In 2001 at Aiktow and Summit, there were 611 'capture histories' by day for serial-number tagged walleye. The estimated daily abundance ranged from 3 to 938 spawners, for a total of 6,734 walleye-days over 13 days. This indicates 2,322 individual spawners, since the average length-of-stay was 2.9 days. No confidence limits were possible, but the standard error was equal to the estimate so they would be wide (see SE'(N) in Pollock et al. 1990). By comparison, an analysis suitable for a 'closed' population at Aiktow and Summit in 2001 estimated about twice that (4,478 walleye by Schnabel method modified by Chapman). The population, however, is not 'closed' since walleye spent only 2.9 days each near the trap-nets during May 3 to 15th.

Many spawners were not resident in the area for the entire 3 week spawning period. At Aiktow and Summit creeks, 25 of 37 fish were recaptured on consecutive days (2-day stay) and only 4 fish were recaptured 5 or more days later. Presumably, walleye left the trap-net area shortly after tagging. They did not likely go 'upstream' and stay, or more should have been caught on the return. They may have returned to the lake after a short stay in the creek mouth.

Length-of-stay is obviously an important factor in daily estimates, as a change from 4 to 3 days affects the number of individuals considerably. Various methods are still being developed or field-tested (see Manske and Schwarz 2000).

Daily estimates were also available for Hitchcock Bay in 2001: 105 capture histories gave estimates of 3 to 678 walleye (average of 255 walleye) on-site each day. This gave a total of 2,044 walleye-days over 8 days, or a likely maximum of 5,350 walleye-days over three weeks. Only 12 fish were recaptured on-site and averaged 5.4-day stays, although 9 others were recaptured at Coteau Bay in the same spawning season. We assumed an overall average of 3 days, implying there were about 1,785 individual spawners in 2001. Again, no confidence intervals were possible as the model had to allow for recruitment and emigration with sparse data.

In 2001 at Hitchcock Bay, some trap-nets had been set along the lakeshore or only a short distance into the bay. Many of the fish caught in this area were transients, rather than spawning residents. In 2002 and 2003, all trap-nets were set well into the bay to catch residents.

Coteau Bay daily estimates were available from 1,420 capture histories for April 30 to May 15 in 2001. An average of 17,272 walleye on-site suggested about 276,000 walleye-days, or about 47,650 individuals each staying 5.8 days. These estimates were too high again, for the same reason as in 1998 (Jensen and Wallace 2001). The standard Jolly-Seber method does not allow for 'temporary emigration' of fish, such as holding non-ripe ones in pens up to 3 days and releasing them some distance from the trap-nets. Recent statistical models may handle such complications, although they require substantially more data.

About 4,200 walleye were tagged in 2001, another 2,000 in 2002, and fewer than 200 in 2003 in the final study year (Table 11). Almost half of these tags were applied at Aiktow and Summit Creeks and Hitchcock and Sage Bays.

For year-to-year estimates, we used adjustments for tag-loss, recruitment of new spawners, and sometimes mortality (for recaptures 2 years after tagging, to estimate the intervening year).

Tag loss: Some tag types were double-tagged and recaptured in enough numbers to estimate tag-loss. When the number of fish with two tags and fish with only one tag are recorded, the loss rate and the number of fish that have lost both tags can be estimated (Seber 1973 p.95).

TCO green tags were applied in 2001 at Coteau Bay and observed in 2002:

Number with two tags remaining = 154
Number with only one remaining = 33
Loss rate = 33 / (33 + 2*154) ~ 9.7 %
Number of fish missing both tags ~ 2

That is, about 2 out of 189 recaptured fish were not identifiable, or about 1 %. About 82% of tagged fish kept both tags and about 17% kept one tag.

TCO yellow tags applied in 2001 at Aiktow and Summit Creeks and observed in 2002 showed a loss rate of only 2.3% (from 21 fish with two and 1 with one tag). That meant that all TCO-tagged fish were identifiable, although the precision of this estimate was poor.

TCO green tags applied in 2001 and observed in 2003 showed a loss rate of 8.7% over two years (from 171 fish with two and 32 with one tag). Note that records of TCO tags and VIE colours may differ from mark-recapture data used for abundance due to sub-sampling.

TSN# and DP (dorsal punched-hole) were applied together as two distinct types (see Seber 1973). Records for 235 recaptured fish showed 92 with TSN#, 67 with DP, and 76 with both. However, the loss rates of 47 % for TSN# and 55% for DP were not credible. The DP mark has been used previously (near both front and back of the dorsal fin) and may have been missed or its origin confused. We used TCO loss rates as proxies for TSN# tags, although a rate of 5% was used since the fewer TSN# tags were applied more carefully.

VIE colours applied in 2002 and observed in 2003 showed a loss rate of 8.5% over one year (from 43 fish with two and 8 with one mark). This rate is similar to TCO tags, so two colours prevent any loss of fish identification over one year.

Recruitment: New recruits without tags would cause over-estimates of abundance if included in counts. The best adjustment would remove the actual % of new recruits for each site and each year. The observed % for recruiting year-classes in 2002 varied and the age at full recruitment seemed imprecise (see Figure 8). Recruits varied from about 25% of spawners at Aiktow and Summit Creeks (averaging females and males) to 20% at Hitchcock and Sage Bays and Coteau Bay.

Table 11. Summary of numbers of walleye observed and tagged, 2001 to 2003.

	Site [a]						
Year	AC & SC		HB & SB		CB		TOTAL
2001							
Number new tags	835		98		3,263		4,196
TSN#	0		98		554		
PIT#	604		0		869		
TCO [b]	YY	231	BB	0	GG	1,840	
2002							
Number observed	654		569		1,543		2,766
Number recaptured	75		102		382		559
TSN#	7		17		92		
PIT#	46		77		105		
TCO	22		8		185		
Number new tags	571		453		651		2,025
PIT#	571		433		160		
VIE [c]	0		OO	20[c]	GG	491	
2003							
Number observed	101		127		1,289		1,517
Number recaptured	19		21		240		279
TSN#	1		1		25		
PIT#	13		19		66		
TCO	YY 4, G 1		BB 0, G 1		GG 94, G 15		
VIE	0		0		GG30, G7, OO3		
Number new tags	68		106		0		174
PIT#	68		105		0		
VIE [d]	0		1		0		

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.
[b] TCO colours were yellow, blue, and green (e.g YY is two yellow tags, G is one green).
[c] VIE colours were 2 orange (HB&SB), 2 green (CB), and 3 red (new site Hamilton Flats in 2003).
[d] When both VIE and PIT# were applied to a fish, only the PIT# was counted.

Mortality: We also used mortality rates and the sums of geometric series to generalize the expected % of recruits. At 20% mortality, female recruits aged 6 would comprise 25% of all spawners up to age 20. At 25% mortality, male recruits aged 5 would be 33% of all spawners to age 14

Abundance: The estimated abundances varied according to tag types, but averaged:
— about 5,800 spawners in Aiktow and Summit (accepted range about 4,000 to 7,800);
— nearly 3,000 in Hitchcock and Sage (accepted range 2,400 to 3,500);
— 10,000 to 12,000 in Coteau (accepted range 7,000 to 14,900)(Table 12).

These estimates are about twice the daily estimates of only 2,322 spawners in Aiktow and Summit Creeks and only 1,785 in Hitchcock Bay in 2001. The intent of the daily approach was to avoid the over-estimate of abundance resulting from too few recaptures if many tagged walleye wandered, especially to sites not fished. If only 80% of walleye homed the next year, a population of 16,000 walleye would be over-estimated by 24%, and the calculated confidence interval would not cover the true abundance.

These estimates for Coteau Bay are lower than the 15,000 estimated for 1998 and 11,000 to possibly 22,000 for 1999 (Jensen and Wallace 2001). The gill-cover (MT) tags used in the earlier study had much higher tag-loss and possible mortality, which would have caused over-estimates of abundance (Ricker 1975). Interestingly, the estimate for 1998 was 12,000 spawners from dorsal-punch (DP) holes used as permanent scars.

A spawning population of about 12,000 walleye in Coteau Bay implies that 100 million eggs collected would be 16 % of all eggs available in this one population (compared to 13 % from 15,000 walleye in Jensen and Wallace 2001).

Mixing: Records of recaptures seemed reliable for visual tag types used in one or two sites, such as the TSN# used at only two sites in 2001. However, PIT# with long alphanumeric serial numbers were difficult to transcribe or search. PIT# tags only included a list of ID#s from the maufacturer to minimize errors from 2002 on. Recaptures were more likely missed with PIT# tags, affecting both abundance and mixing.

Movements from 2001 to 2002 were based on TSN# and TCO tags because all sites used large numbers (2,700 tags overall).

About 90% or more of tagged walleye homed to the same site the next spring (Table 13). The exception was Hitchcock Bay in 2001, which had only 65% or less return as mentioned. Some mixing rates were based on few recaptures and had wide confidence limits.

Adjusting numbers of recaptures for relative fishing effort at each site changed the proportions of mixing only slightly, except again at Hitchcock and Sage Bays. There was only a 2-fold greater chance of tagged fish being recaptured at some sites than others. This rather narrow range is presumably caused a combination of fish abundance and behaviour, and the similarity of water depths and bottom slopes that are suitable for trap-netting at different sites.

Table 12. Abundance of walleye estimated from year-to-year mark-recaptures, 2001 and 2002.

Area and Year	Abundance	95% Confidence limits		Adjustments [b]
AC & SC 2001 [a]		Lower	Upper	
TCO	4,958	3,323	7,347	Recruits 25%
PIT#	6,327	4,769	8,380	Recruits 25%
TCO & PIT#	5,955	4,712	7,520	Recruits 25%
AC & SC 2002				
TCO	1,893	967	3,488	Rec 25% 2x, Mort 25%
TCO & PIT	4,022	2,378	6,658	Rec 25% 2x, Mort 25%
PIT#	7,760	4,283	13,562	Rec 25%
HB & SB 2001				
TSN#	2,390	1,540	3,673	Rec 20%, Loss 5%
HB & SB 2002				
PIT#	3,467	2,259	5,271	Rec 20%
CB 2001				
TSN#	7,008	5,755	8,531	Rec 20%, Loss 5%
PIT#	10,140	8,390	12,250	Recruits 20%
TCO	12,226	10,596	14,110	Recruits 20%
All 3	10,397	9,413	11,483	Rec 20%, Loss 5%
CB 2002				
TSN# 2001	14,924	10,625	20,890	Rec 20%, Mort 20%
VIE	8,366	6,376	10,962	Rec 20%

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.
[b] Recruitment was 20 or 25% (twice over 2 years), Mortality 20 or 25%, and Tag loss 0 or 5%.

Table 13. Movements of tagged walleye between sites over one year.

Tagging Year	Recaptures by site in 2002 [a]		
and Site	AC & SC [b]	HB & SB [b]	CB [b]
2001 without adjustment [c]			
AC & SC	91% (71 - 99)	0% (0 - 15)	9% (1 - 29)
HB & SB	6% (0 - 29)	65% (39 - 86)	29% (10 - 55)
CB	2% (1 - 4)	3% (1 - 6)	95% (92 - 97)
2001 with adjustment [c]			
AC & SC	92% (79 - 97)	0% (0 - 9)	8% (3 - 21)
HB & SB	10% (3 - 30)	55% (34 - 78)	35% (18 - 57)
CB	2% (1 - 4)	2% (1 - 4)	96% (93 - 97)
2001 adjustment data			
Relative catch rates	11 % (Catch 564 from Pop'n of 5,800)	19 % (Catch 569 from Pop'n of 3,000)	13 % (Catch 1543 from Pop'n of 12,000)

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.
[b] 95% confidence limits are shown in parentheses; the limits shown for adjusted % are too narrow because adjustments increased the apparent sample sizes.
[c] Adjustment is for chance of recapture given catches and abundance at recapture site.

Table 14. Mixing of numbers of walleye between sites over one year.

Tagging Year		Recaptures by site in 2002 [a]		
and Site	Population	AC & SC	HB & SB	CB
2001 without adjustment [b]				
AC & SC	5,800	5,278	0	**522**
HB & SB	3,000	180	1,950	**870**
CB	12,000	**240**	**360**	11,400
2001 with adjustment [b]				
AC & SC	5,800	5,336	0	**464**
HB & SB	3,000	300	1,650	**1,050**
CB	12,000	**240**	**240**	11,520

[a] CB is Coteau Bay, AC Aiktow Creek, SC Summit Creek, HB Hitchcock Bay, SB Sage Bay.
[b] Adjustment is for chance of recapture given catches and abundance at recapture site.

The total number of walleye which moved to new sites was estimated from population abundances and proportions that moved. Preliminary estimates suggested a balanced mixing, with equal numbers of walleye into and out of Coteau Bay in the next year. Some of these were reported to various groups during the study (Rob Wallace pers. comm. 2003).

More refined estimates showed that a net in-flow of spawners into Coteau Bay each year from other sites was more likely. The net-inflow was about 800 walleye or 7% of the population in Coteau Bay. This arose when about 1,392 moved in and only 600 moved out (bold numbers in Table 14). Adjusting for the chance of recapture at each site gave a net inflow of about 1,000 walleye. Some estimates of abundance and recapture data indicated a small out-flow, about 300 walleye or 3% of Coteau Bay.

Aiktow and Summit Creeks had either a small net out-flow of about 100 walleye or a smaller in-flow of about 80 walleye, or about 2 % of the population (Table 14). These estimates all depend on population abundances and mixing rates, both of which are imprecise.

In 2003, only 4 of 109 walleye caught at Hamilton Flats had been tagged elsewhere previously. This was not a high rate over the short term and suggested that mixing may diminish with distance, since there were a few thousand tagged walleye still present in the lake.

DISCUSSION

There were differences in the suitability of the types of tags used, from a technical viewpoint (simple application, good retention, reliable detection, low mortality or side-effects) and from a public one (unobtrusive visibility, few tag sores, low cost, and rapid detection by anglers).

The variety of tags provided comparisons of tag-loss and side-effects, but reduced the precision of estimated tag-loss for each and increased the chance of tags being overlooked on recapture. Anglers may also have released tagged fish differentially due to sores caused by some types, or to a desire assist the study by releasing visibly tagged fish but not invisible tags (especially PIT tags).

Some potential complications may under-estimate or over-estimate year-to-year abundances. We had observed previously that walleye tagged with serial numbers in 1998 returned in statistically similar order in 1999 (Jensen and Wallace 2001). When this occurs, only walleye present in that portion of the spawning period are estimated. An under-estimate would also occur if some individual walleye prefer to congregate or spawn near trap-nets and are more likely to be tagged and recaptured. For reliable estimates, all fish should be equally catchable but this is difficult to confirm or correct (Seber 1973 p.82). We have already mentioned the potentially serious over-estimation that would result from low rates of homing, particularly to sites that we did not study.

The problem with the many transients at Hitchcock Bay in 2001 was uncertainty about the definition and number of "resident"spawners. The presumed "staging" of spawners in open water near Qu'Appelle Dam where they were inaccessible to nets made the reliability of within-year estimates unclear and reduced the number tagged from this group for year-to-year estimates.

Some reported spawning abundances can be considerably higher than in Lake Diefenbaker:
- 17,000 or more spawners in Crean - Heart Lakes, SK(Mathias et al. 1985).
- "as many as 20,000" adults in the Montreal River (Lac la Ronge), SK in the 1940-1950 period before a serious decline in numbers (Chen et al. 1984);
- 22,000 adults on spawning grounds of Nipigon River, ON in May 1957 when they "were considered to be abundant" before a serious decline; no spawners were seen in 1964-1966 due to impacts of lamprey and pollution (Ryder 1968 p.1365);
- 78,000 adults in the "entire spawning stock" of the St. Louis River, MN in 1980-82 after historical pollution had been partially cleaned up (Schram et al. 1991).

Lake Diefenbaker was expected to have 187,000 to 562,000 adult walleye lake-wide, based on its habitat and walleye densities observed in other populations (Baccante and Colby 1996). About 23,400 ha is shallower than 15 m and suitable for walleye (49% of the lake at FSL, Royer 1972). About half of North American lakes have from 8 to 24 adult walleye per hectare, suggesting a possible minimum of 187,000 adults.

This number of adults implies many spawning sites if they range from 3,000 to 12,000 spawners each. For example, Swift Current Creek is well known and may have 3,000 spawners (Chen et al. 1984). There is an unknown number of spawning sites, but 37 sites with 5,000 spawners each seems unlikely. Given the erodible shoreline and wind-driven cleaning of substrates, there may be diffuse spawning sites along shore (Penner 1993, Ken Scott pers. comm. 2001), but likely not several thousand spawners at each. So, there may be far fewer walleye in Lake Diefenbaker than in typical walleye lakes and protecting them from over-use becomes important.

Homing is well known in walleye populations, although patterns differ. Homing to a spawning site may be a behaviour learned when first-time spawners follow older walleye, rather than a return to natal sites (Donald Olson and Dennis Schupp and Val Macins in Pyzer 1999). Walleye fry disperse according to wind and water currents, and may not reside long enough at their hatch site to be imprinted. If homing is learned as adults, this complicates our plan to assess the contribution of fry which have been marked and re-stocked into Coteau Bay.

An annual net in-flow of 7% into the Coteau Bay spawning population can be seen as:
— about 1/3 the number of new spawning recruits each year;
— about 1/2 of the total mortality of 15%; or
— replacement of about 1/3 of all spawners over 6 years (the average time that spawners remain in the population given their mortality rate, Ricker 1975 p.32).
It would presumably require a long series of mark-recaptures to confirm these preliminary estimates of mixing (Diffendorfer 1998).

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DISCUSSION

Some ideas of criteria for a contingency plan include:
— a single year of an indicator outside its prediction bounds as a caution (preferably 80 % bounds); a second year outside bounds would trigger action;
— downward trends in indicators, especially numbers of walleye caught, female %, average fecundity, or hatch rates; this could extend to changes in the probability of negative slopes (similar to power-analysis in Peterman 1990);
— changes in egg dry mass or lymphocystis rates, although data will only be periodic;
— individual year-class abundances that are unusually low, although tracking the number of small females would avoid the need to age fish.

Most indexes used by other agencies to assess walleye populations are more suitable for the classification of lakes. Some of these include rates of growth, age or size at maturation, age-class stability, climatic degree-days, mortality rates, and variations in population abundance (Sullivan 2003, Lester et al 2000, Gangl and Pereira 2003).

Identification of other spawning populations and ranking their site suitability and abundance would allow us to extrapolate lake-wide abundance of mature walleye. We had planned for crews with hydro-acoustic expertise to survey reaches of shoreline to detect concentrations of fish and identify species by netting. This would have provided us with suitable fishing sites and data on the number of congregating areas. For several reasons, crews were not available.

A second method we explored was to assume that bays or creeks that warm earlier each spring might attract spawners preferentially. We recorded spring water temperatures at most of our sites, using standardized locations near the open lake but with some protection from cooling spring winds. Useful spring temperature patterns have not yet emerged from this preliminary work. Satellite images of early-spring conditions every 18 days were viewed, although our classification was poor without access to full spectrum data (Lee Kostiuk pers. comm. 2002).

Some anglers remain concerned about two issues: sizes and abundance of walleye in several areas and times of year, and fishing for walleye near Saskatchewan Landing specifically. We recognize that these may indicate underlying biological problems. First, our assessment covered only spawning populations, which are age 6 and older. Available data does not indicate whether the younger walleye which many anglers observe are as abundant as formerly. Further, the effects of recent harvests and catch-and-release fishing are presently unknown. Periodic creel surveys showed that the focus of angling had changed from northern pike to walleye by the early 1980s (Chen 1983). Second, the spawning sites we assessed were near one another in the lower third of the lake. Saskatchewan Landing is located in the riverine area at the upper end of the known range of these walleye spawning populations (Jensen and Wallace 2001). The status of walleye populations in this area may be different.

CONCLUSIONS

Indicators point to healthy spawning populations at all sites examined in the lower part of the lake. There is no way to prove it beyond doubt — just as with human health. The situation may change over time, and our assessment is less reliable for areas further from the study area.

Monitoring of seven indicators at Coteau Bay showed no trends or serious fluctuations since 1991. These include numbers of walleye caught, numbers of males or females caught or spawned, average number of eggs per female, or percentage of eggs hatched. One indicator did raise a cautionary flag: % females was very low in 2000 although it has since 'recovered'. This indicator tends to rise a few years before falling again, which may reflect the passage of strong year-classes, and should be watched.

The monitoring by FCS staff since 1991 has been invaluable for assessment. Observed catch rates probably reflect the available population each year, although experienced staff adjust fishing locations according to conditions. This may be as reliable as fishing in a standardized pattern, and certainly more productive of eggs.

About 16 % of all eggs available in Coteau Bay have been taken in some years. This should be sustainable, since walleye year-classes are not very sensitive to numbers of spawners at moderate to high abundances. Hatchery staff have demonstrated that they can increase the number of eggs collected to meet demands for 100 million or more eggs. But a sustainable approach would be moderate demands to fit the natural availability of eggs.

'Egg dry mass' was the same in Coteau Bay in 2002 as in 1997, and was significantly larger than in Aiktow Creek in 2002. EDM is a feasible index for periodic monitoring. An equivalent 'fry dry mass' index would be simpler and closer to our management interest in the survival of fry after stocking. 'Fry dry mass' should be easier to monitor since eggs are not influenced by female fish length, unlike many lakes.

Handling of walleye both for egg collection and for tagging causes higher rates of infection by viral lymphocystis. The natural rate is low to moderate in Lake Diefenbaker compared to other lakes. Other diseases are not a concern according to the few diagnoses completed. Periodic monitoring should show if the situation remains acceptable, or even improves with the release of infected fish at trap-nets and no plans for more tagging.

Walleye in Aiktow and Summit Creeks are generally longer than those in Hitchcock and sage Bays. In turn, these are similar or maybe longer than those in Coteau Bay and further up-lake at Hamilton Flats. Age compositions and mortality rates reflect healthy populations at all sites. Higher mortality rates at Aiktow and Summit Creeks may simply be anomalies in the samples collected.

The 1990 walleye year-class is strong (relatively abundant) and those of 1993 and 1994 are weak. Nonetheless these are only modérate fluctuations for walleye, which are often affected by spring conditions. The five sites show some variations in year-class strengths, presumably due to local weather and water conditions. An index of year-classes based on age composition should be as suitable as the more typical index based on annual catches of young walleye.

Dorsal spines provided clear growth increments and narrow confidence bands. Age-6 female spawners grew much faster as young fish than their cohorts and age-7 or age-8 females. The likely explanation is earlier maturation by fast-growing individuals. This meant that data for these ages were unsuitable for detecting impacts by rainbow trout on walleye growth.

Tags that were injected and had visual serial numbers or colour codes (TSN# and TCO) were easy to record and had annual tag-loss about 10%. They also caused sores that persisted in many walleye and were sometimes severe. Internal tags (VIE and PIT#) were more awkward to apply, but healed well. VIEs had tag loss slightly less than 10%, while PIT# tag loss was not checked. Use of double-tagging meant that corrections for tag losses were low to negligible.

Abundances estimated from daily mark-recaptures were about 2,300 spawners at Aiktow and Summit Creeks and 1,800 at Hitchcock and Sage Bays. These are about half of estimates based on year-to-year data, and depend on the estimated length-of-stay of walleye. This method does not work reliably in Coteau Bay since fish are penned and not available for daily recapture.

Abundances based on year-to-year data averaged almost 6,000 at Aiktow and Summit Creeks, nearly 3,000 at Hitchcock and Sage Bays, and 10,000 to 12,000 walleye at Coteau Bay in 2001 and 2002. The latter estimate is lower than the 15,000 walleye in 1998, although that previous one may have been too high due to tag loss and mortality.

Estimated abundances varied at each site according to tag type and year. This may be partly due to different tag types being applied to different sizes, or to selective removal of walleye with some tag types by mortality or by anglers. However, there was frequently no explanation.

About 90% or more of tagged walleye homed to the same site the next spring. The walleye which wander may tend to remain at the new site or return to the former. There may be a net flow of 800 to 1,000 spawners into Coteau Bay each year from other sites, although estimates are not precise.

Changes in some other fish species in Coteau Bay are notable, especially increases in yellow perch and white suckers and serious declines in burbot. These changes may also be occurring at other sites but there are no comparable time series of data. Some of these trends are natural outcomes of the ageing of this large, prairie reservoir.

RECOMMENDATIONS

1. Base the annual collection of walleye eggs on the natural availability of eggs. This sets a tone of aiming for sustainability. It may require a review of provincial demands by staff and users for fry stocking.

2. Continue to monitor FCS operations in Coteau Bay, and analyze records each year to detect anomalies. The criteria for concern should be data that fall below updated confidence bands, unless further analysis shows a clear explanation. The most useful indicators are probably walleye catch rates for given effort and water-level, the proportion of suitable females in the catch, average number of eggs per female, and percentage of successful hatch.

3. Periodically collect data on indicators of egg or fry quality, using 'egg dry mass' or 'fry dry mass' unless more suitable ones are developed. Any new index should be checked for correlation with indicators used in 1997 and 2002. Collections every three to five years should suffice.

4. Record rates of lymphocystis and other disease symptoms every few years. If higher rates or new symptoms emerge, collect suitable specimens for necropsy and any relevant analysis. Observations every three to five years should suffice, unless problems are seen earlier.

5. Design and adopt a contingency plan for FCS operations that includes criteria, alternative actions, and a process for decisions. Monitoring will be useful if there are criteria for action and if some foreseeable actions are known before they are needed.

6. Continue to mark hatchery fry that are re-stocked into Coteau Bay, and catch and examine enough suitably aged walleye to determine their source. The contribution of hatchery fry can be relative to natural fry, since assessing their survival would be difficult and unnecessary.

7. Consider reviewing any recent and future data from other lakes to detect any regional correlations of year-class strengths among lakes or to climatic variables. This would place the present variations in context and alert staff and others in future to upcoming weak year-classes.

8. Monitor future angling tournaments for tag recaptures if feasible. Reasonable numbers of tagged walleye will be catchable for five or more years, given the high survival rate of spawners and life-span of some tags (especially PIT tags).

9. Consider a general review or survey that assesses the abundances and sizes of walleye and the areas of this lake that most concern anglers and others.

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